Calhoun: The NPS Institutional Archive

Theses and Dissertations Thesis Collection

2013-09

An inter-rater comparison of DoD Human Factors Analysis and Classification System (HFACS) and Human Factors Analysis and Classification System Maritime (HFACS-M)

Bilbro, Jason

Monterey, California: Naval Postgraduate School

Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AN INTER-RATER COMPARISON OF DOD HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) AND HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM—MARITIME (HFACS-M)

by

Jason Bilbro

September 2013

Thesis Advisor:	Lawrence G. Shattuck
Second Reader:	Samuel E. Buttrey

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2013	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE
AN INTER-RATER COMPARISON OF DOD HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) AND HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM – MARITIME (HFACS-M)

5. FUNDING NUMBERS

6. AUTHOR(S) Jason Bilbro

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Human error has been identified as a factor in virtually every major maritime mishap over the past decade. The Department of Defense (DoD) currently employs the Human Factors Analysis and Classification System (HFACS) taxonomy to identify and quantify human error in major mishaps. HFACS divides errors into categories, sub-codes, and nano-codes. The generic nature of DoD HFACS raises the question of whether or not a domain-specific version for the surface Navy could be applied more consistently. Twenty-eight subjects (14 Surface Warfare Officers (SWOs) and 14 non-SWOs) employed either DoD HFACS or a developmental maritime domain specific version, HFACS-M, to classify findings in a National Transportation Safety Board (NTSB) maritime accident investigation. Fleiss' Kappa was used to determine inter-rater reliability among subjects. The results of this study revealed that SWOs using HFACS-M had a higher inter-rater reliability (10.9%, 7.3%, and 6.5%) at every classification level than non-SWOs. HFACS-M itself was also shown to have a slightly higher overall inter-rater reliability (5.7%, 7.4%, and 3.6%) than DoD HFACS. The research concluded that although HFACS-M performed well, further testing is necessary to validate it.

14. SUBJECT TERMS Human Systems Integration, Safety, Mishaps, Human Factors, Human Factors Analysis and Classification System (HFACS)

15. NUMBER OF PAGES 125

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

AN INTER-RATER COMPARISON OF DOD HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) AND HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM—MARITIME (HFACS-M)

Jason Bilbro
Lieutenant, United States Navy
B.A., University of Missouri, 2007

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN HUMAN SYSTEMS INTEGRATION

from the

NAVAL POSTGRADUATE SCHOOL
September 2013

Author: Jason Bilbro

Approved by: Lawrence G. Shattuck
Thesis Advisor

Samuel E. Buttrey
Second Reader

Robert F. Dell
Chair, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Human error has been identified as a factor in virtually every major maritime mishap over the past decade. The Department of Defense (DoD) currently employs the Human Factors Analysis and Classification System (HFACS) taxonomy to identify and quantify human error in major mishaps. HFACS divides errors into categories, sub-codes, and nano-codes. The generic nature of DoD HFACS raises the question of whether or not a domain-specific version for the surface Navy could be applied more consistently. Twenty-eight subjects (14 Surface Warfare Officers (SWOs) and 14 non-SWOs) employed either DoD HFACS or a developmental maritime domain specific version, HFACS-M, to classify findings in a National Transportation Safety Board (NTSB) maritime accident investigation. Fleiss' Kappa was used to determine inter-rater reliability among subjects. The results of this study revealed that SWOs using HFACS-M had a higher inter-rater reliability (10.9%, 7.3%, and 6.5%) at every classification level than non-SWOs. HFACS-M itself was also shown to have a slightly higher overall inter-rater reliability (5.7%, 7.4%, and 3.6%) than DoD HFACS. The research concluded that although HFACS-M performed well, further testing is necessary to validate it.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

AFFF	Aqueous Film Forming Foam
DDG	Guided Missile Destroyer
DoD	Department of Defense
DON	Department of Navy
HFACS	Human Factors Analysis and Classification System
HFACS-M	Human Factors Analysis and Classification System–Maritime
HFE	Human Factors Engineering
IDCAM	Incident Cause Analysis Method
IRB	Institutional Review Board
ISIC	Immediate Superiors in Command
JOOD	Junior Officer of the Deck
MPT	Manpower, Personnel and Training
MRC	Maintenance Requirement Card
MSC	Military Sealift Command
NAVSAFCEN	Naval Safety Center
NCIS	Naval Criminal Investigative Service
NTSB	National Transportation Safety Board
OOD	Officer of the Deck
PFA	Physical Fitness Assessment
PFT	Physical Fitness Testing
PRT	Physical Readiness Test
PT	Physical Training
SIB	Safety Investigation Boards
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SWO	Surface Warfare Officer
TYCOMS	Type Commanders
U.S.	United States
USNS	United States Naval Ships

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

An analysis of accident investigations throughout the surface Navy suggests that nearly every mishap contains some level of human error. To identify mishaps properly for mitigation and elimination, the Navy must have an effective error classification system. The Department of Defense (DoD) has implemented the Human Factors Analysis and Classification System (HFACS) to address this very issue. HFACS asserts that errors arise in four distinct categories: organizational influences, supervision, existing preconditions, or the very acts themselves. Each category is divided into sub-codes, and each sub-code into nano-codes to identify specific errors. HFACS was originally developed for naval aviation but has been adapted for use in all branches of service. Several published studies suggest that domain-specific error classification systems may lead to higher inter-rater reliability. To this end, a maritime specific version of HFACS, HFACS-M, was developed.

Twenty-eight students from the Naval Postgraduate School (14 Surface Warfare Officers (SWOs) and 14 non-SWOs) received training on either DoD HFACS or HFACS-M and then were asked to employ them in a real-world scenario. Subjects were asked to classify 11 findings in a National Transportation Safety Board maritime accident investigation using one of the taxonomies to assign an appropriate nano-code. The subjects' responses were compiled into two tables, one for HFACS, and one for HFACS-M. The tables were then separated between SWOs and non-SWOs. Inter-rater reliability was calculated for each error classification taxonomy using Fleiss' Kappa. Overall inter-rater reliability and inter-rater reliability for SWOs and non-SWOs were calculated. This process was repeated at the sub-code and category level.

Analysis showed that, of the two taxonomies, HFACS-M had a slightly higher overall inter-rater reliability at every level (5.7%, 7.4%, and 2.8%) than DoD HFACS. When using the domain-specific taxonomy, SWOs displayed a

higher inter-rater reliability (10.9%, 7.4%, and 6.5%) than non-SWOs. Non-SWOs did, however, have a slightly higher inter-rater reliability (10.2%, 4.3%, and 8.4%) when employing DoD HFACS.

The research concluded that, in this particular study, SWOs performed slightly better at every level of analysis than non-SWOs when applying the domain-specific error classification taxonomy. It was also found that HFACS-M had a slightly higher overall inter-rater reliability at each level than DoD HFACS. Due to a small sample size and lack of trained raters, it cannot be stated conclusively that HFACS-M is a significantly better method for classifying error in the surface Navy. It can be concluded, however, that the results of this study support the need for further research. Additionally, the Navy should attempt to address the gaps in latent distal errors and maintenance-specific errors.

ACKNOWLEDGMENTS

This work is dedicated to my wife and her steadfast love and devotion these past few years. I would not be here without her.

Thank you to my two wonderful parents and the example that they have set for me. I hope to one day be able to measure up to it.

I would also like to thank the superb leaders and mentors I have had over the past six years: Lawrence Shattuck, Hank Adams, Brent DeVore, John Zuzich, and Cory Blaser.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. OVERVIEW

Human error has been a cause in virtually every significant mishap within the surface Navy for the past several decades. Based on Naval Safety Center data from January 1992 through December 1996, human error was found to be a factor in 100% of all recorded incidents (Lacy, 1998). As such, the reduction of human error has been a key focus of the Navy, as well as other organizations for many years.

Reason's research into human error brought him to the belief that in a perfect world, mishaps are nearly always preventable. He saw each accident as an event that could be prevented at different points. Much like slices of Swiss cheese, these layers were filled with holes (Figure 1) in the real world. Reason asserted that these holes were due to some combination of latent and active failures (Reason, 1997).

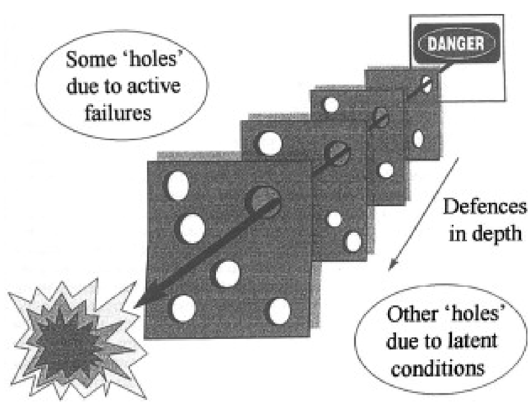


Figure 1. Reason's original "Swiss Cheese" model (From Reason, 1997)

Reason's theory was a catalyst for the team of Shappell and Wiegmann, who took the basics of the theory and developed a method for attributing causality in accidents (Shappell & Wiegmann, 2001). The Department of Defense (DoD) Human Factors Analysis and Classification System (HFACS) is a taxonomy for classifying mishaps. Using the "Swiss cheese" model as a starting point, Shappell and Wiegmann assigned names to each of the layers, or levels (Figure 2). DoD HFACS consists of four levels: organizational influences, supervision, preconditions, and acts; the holes within each of which lead to the eventual mishap. At each level, the taxonomy is broken down into categories, or sub-codes, and then into nano-codes (Shappell & Wiegmann, 2001). The surface Navy currently uses DoD HFACS in classifying all its major mishaps (Department of Defense, 2005).

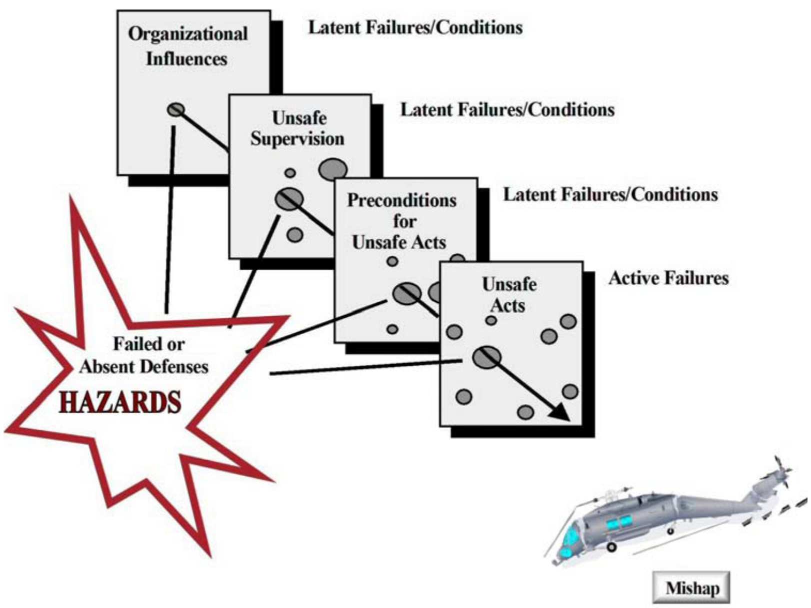


Figure 2. The "Swiss Cheese" model—HFACS version (After Reason, 1990; DoD, 2005)

Since its creation, HFACS has been widely researched, with more than 90 articles published on the subject. The research surrounding HFACS is effectively split into two categories, DoD HFACS and hybrid versions of DoD HFACS. Next, the research is further broken down into analysis using the HFACS sub-codes and analysis using nano-codes. Of these four possible combinations, the most prevalent research concerns DoD HFACS at the sub-code level, while the least common examines non-DoD HFACS at the nano-code level.

The majority of HFACS research presupposes the mishap ratings are accurate. Many studies use a consensus method whereby a group of experts discusses the factors of the mishap before arriving at a final decision, much like what would occur at a mishap investigation board. Coding at the categorical level has been shown to have less inter-rater error, presumably due to the small number of sub-codes (19) compared to the large number of nano-codes (144).

Not all researchers presuppose sufficient inter-rater reliability, however. O'Connor has published several papers testing the reliability, utility, and validity of HFACS using trained raters, simulated mishap boards, and experienced aviators. O'Connor's findings suggest the need for more robust HFACS training, particularly for end users, and a more robust verification and validation process for the evaluation system being used—HFACS or otherwise (O'Connor, 2008; O'Connor, Walliser, & Philips, 2010; O'Connor & Walker, 2011).

Salmon, Cornelissen, and Trotter (2012) also questioned HFACS' reliability. The researchers conducted a comparison of several accident analysis methods, including Accimap, HFACS, and STAMP. Although they concluded that HFACS was a better system to use in a large organization, such as the DoD, they raised questions about HFACS' reliability and were concerned about the lack of domain specificity outside of aviation.

Finally, in one of the most recent studies utilizing HFACS, Griggs (2012) investigated mishaps within the commercial maritime sector and applied HFACS to a series of 48 mishaps. His research determined that, "in order to improve the reliability of HFACS, the taxonomy needs to be relevant to the maritime community" (Griggs, 2012, p. 85).

B. BACKGROUND

Accidents are an unfortunate reality within the United States (U.S.) Navy, and repair funds are allotted each year to cover the costs. Unfortunately, as technology advances, the cost to repair systems involved in these mishaps increases exponentially.

Failure to learn from past mishaps all but ensures that those mishaps will be repeated in time. To identify and prevent the root cause of hazards that result in major mishaps properly, the Navy convenes safety investigation boards (SIB) for each of the following:

1. All on-duty Class A mishaps on or off a government installation (while performing official duties); in commissioned and pre-commissioned U.S. Navy ships after delivery; United States Naval Ships (USNS) with federal civilian mariner crews in the Military Sealift Command (MSC); Navy-owned experimental and small craft; and the ship's embarked equipment, boats, and landing craft, or leased boats.

2. Military death that occurs during or as the result of a medical event that occurs within one hour after completion of any command-directed remedial physical training (PT), physical readiness test (PRT), physical fitness testing (PFT), physical fitness assessment (PFA) or command-sponsored activity during normal working hours regardless of any pre-existing medical condition.

3. On-duty injury where death or permanent total disability is likely to occur, or where damage estimates may be expected to exceed one million dollars.

4. Hospitalization, beyond observation, of three or more personnel, at least one of who is a DoD civilian, involved in a single mishap.

5. All explosives mishaps, all ordnance impacting off range and all live fire mishaps resulting in an injury.

6. Any mishap that a controlling command (as defined in paragraph 1005.6) determines requires a more thorough investigation and report, beyond that provided by a command’s safety investigator. (Department of the Navy, p. 6-1, 2005)

Upon concluding, each SIB produces a list of findings and follow-on recommendations. The SIB analyzes these findings to determine which hazards were causal to the mishap, and which were contributory (did not directly cause the incident). The SIB then converts the causal and contributory factors to nano-codes using HFACS (Department of the Navy, p. A-15, 2005).

The instruction that governs the SIB process provides guidance with respect to the board's composition. The composition is required to be as follows:

1. Minimum composition of an SIB is three members; however, five is preferred.

2. The appointing authority and senior member of the board can confer and agree on board appointees based on the type and severity of the mishap.

3. For afloat mishaps, all members must be commissioned Officers. If the mishap involves more than one naval command, a Navy, Marine, or MSC representative as appropriate, shall be a member of the SIB.

4. The senior member appointed to the SIB shall not be from mishap command. All SIBs shall consist of:

    a. A senior member, who shall be a commissioned Officer (0-5 or above), a senior civilian (GS-13 or higher), or a senior official in MSC as appropriate.

        (1) A military senior member of a Navy SIB shall be senior to the commanding officer of the command or unit involved in the mishap.

        (2) The senior member of a Marine Corps SIB shall be a Marine Corps officer or a senior civilian (GS-13 or higher), and shall be equal to or senior in grade to the commander of the mishap unit.

        (3) In cases where the senior member requirement cannot be met, the appointing authority shall request a waiver from the appropriate controlling command.

    b. At least two additional members (one of whom could be a subject matter expert (SME) on equipment, systems or procedures). (DON, p. 6-3, 2005).

These requirements present several potential issues. First, none of the members is required to have any background or training in HFACS or investigative procedures (Department of the Navy, p. 6-3, 2005). This board composition policy creates the potential for incorrect HFACS coding. Secondly, HFACS, now called DoD HFACS, is used throughout all branches of military service and contains generic and non-domain specific codes, which leads to the greater likelihood of erroneous coding.

C. PROBLEM STATEMENT

The HFACS taxonomy converts qualitative mishap data to categorical data for the purpose of analysis. The results of these analyses are used to help decision makers determine how money should be spent to prevent future mishaps. If a mishap is coded incorrectly, that information is entered into a database and could lead to incorrect assumptions when analyzed. Given the low inter-rater reliability found in several studies using DoD HFACS (as low as 36% overall and as low as 22.5% for causal factor agreement), it is imperative that the reasons for this disparity be investigated, and methods to improve reliability be explored (Baysari, Caponecchia, McIntosh, & Wilson, 2009; O'Connor, 2008; O'Connor et al., 2010; O'Connor et al., 2011).

This study seeks to gain insight into the existing claims of sub-optimal inter-rater reliability when using HFACS (Baysari et al., 2009; O'Connor, 2008; O'Connor et al., 2010; O'Connor et al., 2011). To inform decision makers correctly about where to spend tax dollars, mishap coding must be accurate. This study also introduces a maritime-specific version of HFACS for use in the surface Navy, referred to as HFACS-M (maritime), in an effort to observe whether or not a domain-specific version of HFACS results in increased inter-rater reliability. The study also considers the role of training in HFACS coding.

D. OBJECTIVES

The purpose of this thesis is to compare the inter-rater reliability, usability, and validity of HFACS and HFACS-M, which is a modification to HFACS developed by the author and tailored specifically to surface ship mishaps. The objective is to use the results to identify any possible gaps in the human error taxonomies for the surface Navy. The results will lead to updated taxonomies to ensure that the U.S. Navy is able to identify human error correctly and reduce the number of mishaps in the future.

E. RESEARCH QUESTIONS

To identify potential gaps, overlaps, and errors within HFACS and HFACS-M, this study attempts to answer the following research questions.

- Do Surface Warfare Officers (SWOs) and Non-SWOs show the same consistency when applying DoD HFACS?
- What errors, overlaps, or gaps, if any, currently exist in DoD HFACS?
- Does a tailored version of HFACS result in increased inter-rater reliability when classifying mishaps within the surface Navy? Why or why not?

F. SCOPE AND LIMITATIONS

This research was limited to the results of the statistical analysis of the data collected from two case studies. Although this research focused on accident analysis within the surface Navy, Naval Safety Center data for major afloat mishaps was restricted. This research focused on the HFACS classification of Class A Mishaps as defined by the current version of OPNAVINST 5102, the Navy and Marine Corps Mishap and Safety Investigation, Reporting, and Record Keeping Manual (Department of the Navy, 2005).

G. HSI

This section discusses the applicable domains of HSI which pertain to this research. More specifically, the areas of Manpower, Personnel and Training (MPT) and Human Factors Engineering (HFE) are considered in this thesis.

1. Manpower, Personnel, and Training

The manpower domain of HSI seeks to develop systems that “optimize manpower and keep human resource costs at affordable levels” (DAU, 2009). An example of a manpower issue is determining the optimal number of sonar technicians required onboard a Guided Missile Destroyer (DDG) to fill three watch sections. Manpower is an important factor in mishap investigation. Many times human error occurs because Sailors are overworked or severely stressed. Overwork in military settings can often be attributed to the improper manning of a system. Improper manning has been shown to lead directly to an increase in safety related mishaps (Lazzaretti, 2008).

The personnel domain of HSI differs from manpower in that it focuses on “human aptitudes (i.e., cognitive, physical, and sensory capabilities), knowledge, skills, abilities, and experience levels that are needed to properly perform job tasks” (Defense Acquisition University, 2009). From a human error perspective, the selection of Sailors and Officers with inappropriate qualifications and experience levels is tantamount to ensuring a mishap will occur in due time.

The DAU defines training as “any activity that results in enabling users, operators, maintainers, leaders and support personnel, to acquire, gain or enhance knowledge, skills, and concurrently develops their cognitive, physical, sensory, team dynamics and adaptive abilities to conduct joint operations and achieve maximized and fiscally sustainable system life cycles” (Defense Acquisition University, 2009). As systems employ more technology, the number of personnel needed to operate, maintain, and support the system should decrease. To balance this, however, more training is required. In the surface Navy, command wide, departmental, and divisional training provide invaluable knowledge to shipboard personnel. Failure to provide specific training leads to human error, which leads to mishaps.

2. Human Factors Engineering

HFE is the HSI domain that supports many of the other domains. HFE seeks to ensure systems “capitalize on and do not exceed the abilities (cognitive, physical, sensory, and team dynamic) of the user population” (Defense Acquisition University, 2009). In systems that have had HFE applied properly during the design process, a significant reduction often occurs of either cognitive or physical workload, or both. Consequently, failing to apply proper HFE during system development can be the cause of mishaps due to physical or cognitive overload of the human.

H. ORGANIZATION

This thesis is divided into six chapters. Chapter I provides a synopsis of human error research and some background on the development and uses of HFACS. Chapter II provides a review of the available research on HFACS. Chapter III explains how the HFACS-M taxonomy was developed and the methodology used to evaluate HFACS and HFACS-M. Chapter IV provides an analysis of the resulting data, and addresses the significant issues uncovered by the research. Chapter V discusses the implications of the study’s results. Chapter VI offers conclusions and recommendations for future research.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE REVIEW

A. MISHAPS

Mishaps comprise the largest unintended costs for the surface Navy today. In times of financial constraints, the Navy cannot afford to spend tax dollars on incidents that should not have occurred, given proper planning, training, and preparation. Mishaps, however, are an inevitable part of any organization. As Reason noted, organizational accidents are “comparatively rare, but often catastrophic, events that occur within complex modern technologies” (Reason, 1997, p. 1).

Reason explained his theory of how mishaps occur using the terms hazards, defenses, and losses (Figure 3).

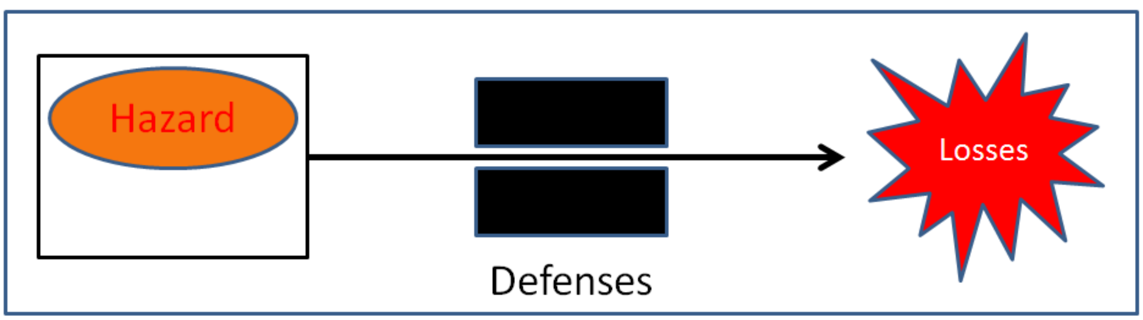


Figure 3. Relationship between hazards, defenses, and losses (From Reason, 1997)

A hazard is a potential mishap or something that could go wrong if not prevented. In the surface Navy, such a hazard is a ship running aground, or colliding with another ship. Losses are the result of an undefended or unprevented hazard. Losses come in the form of injury or loss of life to personnel or damage to equipment.

Defenses, on their most basic level, are created to prevent losses and, as Reason explains, serve one or more specific functions. First, they “create an understanding and awareness of local hazards” (Reason, 1997, p. 7). In the surface Navy, these defenses could be a Local Notice to Mariners report, Coast Guard broadcast or warning, or even a Naval Criminal Investigative Service (NCIS) port brief before sailors go ashore. Second, they provide guidance on safe operation that could be a Navy standard operating procedure (SOP), maintenance requirement card (MRC), or a safety checklist. Third, Reason asserts that defenses also “provide alarms and warnings when danger is imminent” (Reason, 1997, p. 7) that include tank low-level alarms, smoke detection and heat detection sensors, and chemical detection units on engineering equipment. Fourth, these defenses will return the system to a normal operating state following an emergency, which includes releasing fire zone doors following a fire, or recycling vent dampers following a missile launch. Defenses also act as barriers, primarily physical ones, to prevent the loss from actually occurring or to mitigate it. In the fleet, these types of defenses could be a firing cutout, which prevents the system from engaging the superstructure of a ship, or any redundant safety measure to prevent spills of chemicals or fuels. In some situations, defenses are needed “to contain and eliminate the hazards should they escape this barrier” (Reason, 1997, p. 7), which can be a floating oil barrier placed around a ship when it pulls alongside a pier, or an agent, such as Halon or aqueous film forming foam (AFFF), which are designed to eliminate or contain fires. Finally, defenses provide a way to exit an area or save human lives in the event the primary and secondary barriers fail (Reason, 1997) that can be implemented through escape trunks or scuttles, first aid or eyewash stations, life rafts, and distress beacons.

Defenses, however, are not perfect in practice. Defenses are often operated by humans who are prone to error. Additionally, many defenses require some amount of warning time to be fully activated or effective. To this end, Reason developed the concept of the “Swiss Cheese Model” (Reason, 1997).

Figure 1 shows the basic concept of the Swiss cheese model, which follows from his initial established relationship between, hazards, defenses, and losses. Defenses (Swiss cheese) have holes resulting from active or latent failures in the defenses. As Reason explains, accident causation is dynamic, and can be triggered locally, occur from defects in the defenses themselves, or be caused by atypical conditions (Reason, 1990).

Reason developed a model to explain how the hazard to loss process worked in relation to latent and active failures (Figure 4). The triangle portion of the figure represents the factors or conditions leading up to an event (represented by the rectangle at the top). Latent or active, these failures work together to create an error chain that eventually resulted in a loss (Reason, 1997).

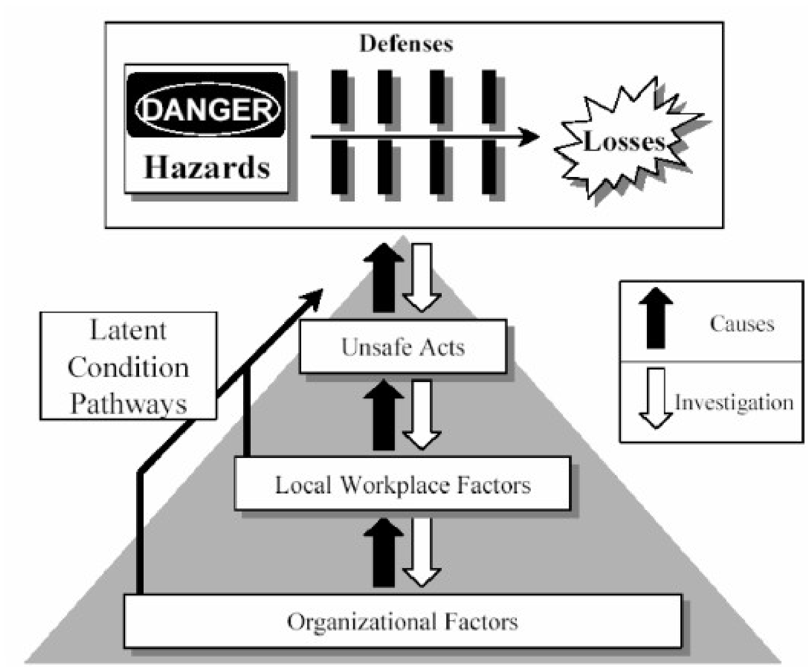


Figure 4. Stages in the development and investigation of an organizational accident (From Reason, 1997, p. 17)

As an example, a ship has been extended on deployment, which has taken its toll on the crew (latent, organizational factor). The helmsman has had insufficient sleep (latent, local workplace factor) as he steers the ship late at night. The Conning Officer is supposed to be watching the navigation situation, but is preoccupied by his upcoming Surface Warfare Officer (SWO) board, and is not paying attention (active, local workplace factor). The ship is transiting a narrow channel and strays into shoal water on its starboard side due to the helmsman nodding off with no one paying attention to him (active, unsafe act). The Officer of the Deck (OOD) and Junior Officer of the Deck (JOOD) stand out on the port bridge wing and have a discussion about the NCAA Basketball Tournament currently going on (active, local workplace factor). The resulting loss is a grounding of the ship, millions of dollars in repairs, and the end of several careers.

B. ACCIDENT INVESTIGATION

In the event a major mishap does occur within the surface Navy, an investigation is required. The purpose of this investigation is to "reveal hazards that could cause future mishaps" (Department of the Navy, 1-1, 2005).

In a perfect world, Reason's model (Figure 5) simply works in reverse, in that an investigation is concerned. A loss is realized (mishap itself), and then analyzed to determine what latent and active failures in the layers of defenses occurred to identify the potential hazard (Reason, 1997).

The unfortunate reality, as Schmorrow accurately explained, is that accident investigation does not happen in a perfect world, or vacuum. Far from it, in fact. Accident investigation is influenced by many factors including (but not limited to) inherent bias, time constraints and the post-hoc nature of the investigation itself, as well as the accident-reporting model being used (Schmorrow, 1998).

According to Schmorrow, "the perceptions of individual accident investigators can confound the goals of an accident investigation" (Schmorrow, 1998, p. 14). For instance, a civilian engineer looking at a collision will almost instinctively focus on the most familiar systems. This bias could lead to overlooking HSI issues that actually contributed to the mishap. Additionally, previous experience or inexperience with particular types of accidents can lead to incorrect conclusions. If experience tells the investigator that 80–90% of accidents have been attributed to human error, a predisposition may find fault in crew members where it may not exist (Schmorrow, 1998).

Time and timing also play significant parts in the investigatory process. As investigations are generally only conducted in relation to catastrophic events, such as the collision or grounding of a ship, the pressure to conduct the investigation in a timely manner is significant. The Navy, as would any organization, wants to find out what went wrong to prevent that loss from happening again, which can cause undue stress on the investigators, and potentially lead them to overlook or miss something. Additionally, the post-hoc nature of the process itself can hamper the truth. If a member or members of the bridge watch team were intoxicated at the time of the incident, but not given a breathalyzer test at the time, it may not be possible to prove that alcohol contributed to the incident. Additionally, part of the nature of the Navy is the sea, the very environment in which it operates. Tides and currents can quickly and easily wash away evidence that may be vital to recreate the story of what happened.

The last major factor of an accident investigation is the accident-reporting model being used. Various forms, models, formats, and procedures are prevalent in the field of accident investigation. This raises at least two key questions. First, what if the investigation produces results not consistent with the reporting model? Second, if the model tells the investigators what they are “supposed” to find, will they then shape their results to fit that model?

C. HFACS

HFACS was developed by Shappell and Wiegmann and is based on Reason’s (1990) previously described model of human error. The purpose of HFACS is to establish a “comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents” (Shappell & Wiegmann, 2001). Originally developed for use in the Naval Service (Navy and Marine Corps aviation), HFACS is now required to be used across all branches of service for the classification of human error in accidents (DoD, 2005). The original version has been adapted to an all-inclusive version that can be used in land, air, surface, and sub-surface accidents.

Several other methods of accident classification currently in use in the civilian sector are worth mentioning. Accimap was developed by Rasmussen in 1997 and divides safety within a given system into levels consisting of government policy and budgeting, regulatory bodies and associations, local area government planning and budgeting, technical and operational management, physical processes and actor activities, and equipment and surroundings. This method of error analysis is generic and does not use a taxonomy (Salmon et al., 2012).

STAMP is a second method of mishap classification, and focuses on control as the primary reason for failures. These controls are divided into managerial, organizational, physical, operational, and manufacturing. The final description produced by this method highlights the overall control structure of a system, and which parts yielded the failure in question (Salmon et al., 2012).

As HFACS is the only error taxonomy currently in use by the DoD, it will be the focus of this research.

1. Structure and Usage

HFACS bridges the gap between Reason’s theory and the actual practice of classifying human error in accident investigation. To this end, the HFACS framework divides Reason’s model into four levels of human error: organizational influences, supervision, preconditions, and acts. Listed under each of these categories are nano-codes that allow for greater specificity as to the nature of the latent or active failure that contributed to the mishap.

a. Organizational Influences

Organizational Influences (Figure 5) fall under Reason's latent failures. Decisions made by numbered Fleet Commanders, Type Commanders (TYCOMS), and even Immediate Superiors in Command (ISICs) can eventually lead to mishaps.

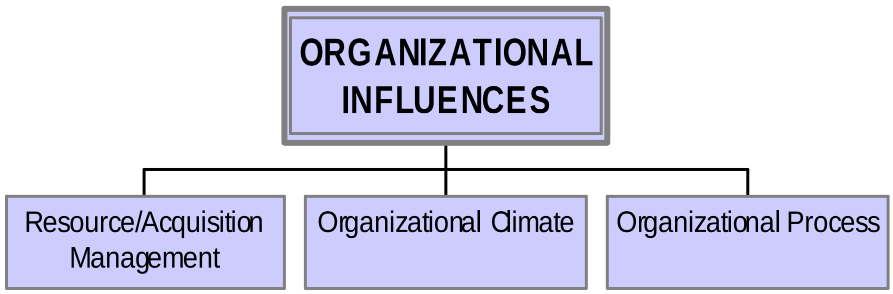


Figure 5. Organizational factors influencing accidents

Resource and Acquisition Management refers to decision making regarding equipment purchases, upgrades, upkeep, and general fiscal management. Examples of nano-codes include inadequate personnel recruiting policies, insufficient support facilities and equipment, failure to provide sufficient funding, failure to remove or upgrade antiquated equipment, and purchasing poorly designed or unsuitable equipment (Naval Safety Center, 2007).

Organizational climate refers to the "atmosphere" within an organization. A command's climate often tells a great deal about it. Organizational climate issues influencing mishaps may include over-confidence in equipment, unclear organizational structure, and undue pressure or demand for mission accomplishment (Naval Safety Center, 2007).

Similarly, the processes of an organization may set up commands in the lower echelons for failure. Unsafe conditions due to high operational tempo, inadequate procedural guidance, unsatisfactory program management, or lack of formal training can all have long-term and unintended impacts (Naval Safety Center, 2007).

b. Supervision

Supervision, shown in Figure 6, more specifically at the command level, has a direct impact on safety and risk management within that command. Supervisors failing to adhere to rules and regulations, as well as failing to require their subordinates to do the same, may set their commands up for catastrophic failure.

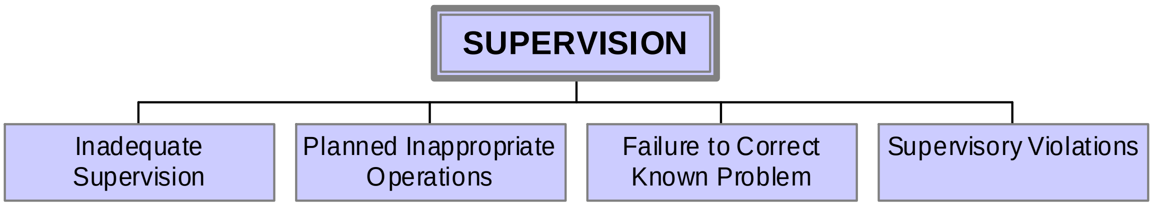


Figure 6. Categories of unsafe supervision

Inadequate supervision and leadership can quickly lead to disaster. In high stress situations or instances when subordinates are relatively unfamiliar with the unfolding situation (inexperienced), supervision is instrumental in preventing potential mishaps. Lack of training, guidance, policy, and even personality conflicts are examples of inadequate supervision.

Risk arises when inappropriate operations are planned. If a supervisor selects an individual without the requisite experience level for a task, authorizes an unnecessary hazard, or directs actions to be taken outside the capabilities of equipment, a mishap is likely to follow.

Similarly, it is incumbent upon supervisors to correct issues brought to light. Failing to correct risky behavior or unsafe practices by subordinates can have catastrophic consequences.

Lastly, violating or intentionally disregarding guidance or policies creates undue risk within a command. Failing to enforce rules, espousing "tribal knowledge" over written instructions, or directing violations of standard policies, create risk that can lead to eventual disaster (Naval Safety Center, 2007).

c. Preconditions

Latent or potential hazards exist all around. As Figure 7 helps illustrate, in a high-tempo and complex organization, such as the surface Navy, both the physical and technical environment can play significant roles in causing mishaps. Personal issues existing within individuals and among individuals in an organization also can contribute to mishaps.

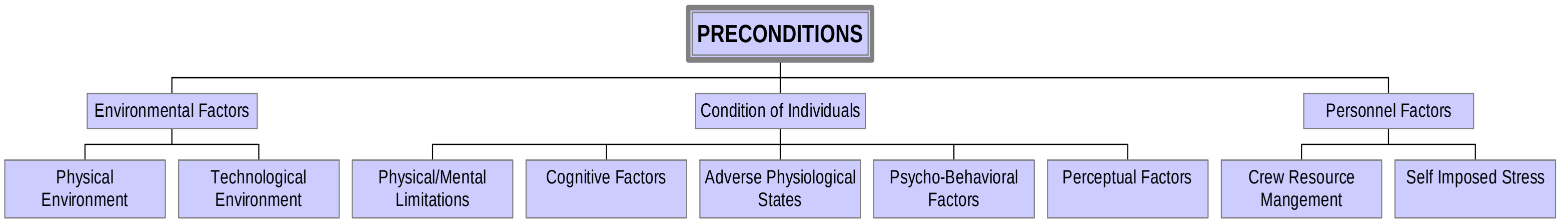


Figure 7. Categories of preconditions for unsafe acts

(1) Environmental Factors. On the environmental side, weather and the ambient environment within a ship are rife with latent hazards. In addition, flaws in equipment design can lie dormant for months or years but can eventually contribute to a mishap. Cold and heat stress, restricted visibility, lighting or backscatter, equipment interface issues (HFE), and instrumentation and warning issues are possible technical preconditions for a mishap.

(2) Condition of Individuals. The largest set of preconditions comes, unsurprisingly, from individuals. Such factors include physical or mental limitations, cognitive factors, adverse physical states, psycho-behavioral factors, and perceptual factors.

Physically, humans have limitations. Be it with memory, learning rate, coordination, or even body size, an individual's capabilities, or lack thereof, can be a precursor for failure, given the right situation.

Issues with how an individual perceives a given situation can prove to be risky as well. Spatial disorientation, coupled with misinterpreting or misreading instruments, and misperceiving a changing environment can cause individuals to respond incorrectly for a given situation, eventually leading to disaster.

Even an individual's personality, motivation level, and other psychosocial issues or psychological disorders can prove to be a source of risk given the proper situation. Emotional state, excess aggression, overconfidence, and complacency are potential factors within individuals that can impact decisions and create added risk.

The final precondition within individuals deals directly with physiological states. Existing medical or physiological conditions include the effects of prescribed drugs, overexertion, motion sickness, and dehydration.

(3) Personnel Factors. The last category of preconditions exists among personnel. Communication, coordinating and planning, as well as self-imposed stress, must be considered factors during accident investigation, as they can play a major role in mishaps. Self-imposed stress takes many forms. Alcohol, improper diet, illegal drugs, and even the fitness level of personnel can all become precursors for serious incidents, given the right prevailing circumstances.

One of the largest and most common sections of precursors is those of coordination, communication and planning. Lack of assertiveness, failure to communicate key information, inadequate planning, as well as failing to re-assess situations as they begin to change, can all lead to mishaps (Naval Safety Center, 2007).

d. Acts

Acts are shown in Figure 8. Acts are the actions or decisions that directly lead to an accident. Acts, or unsafe acts, are categorized within DoD HFACS as either errors or violations.

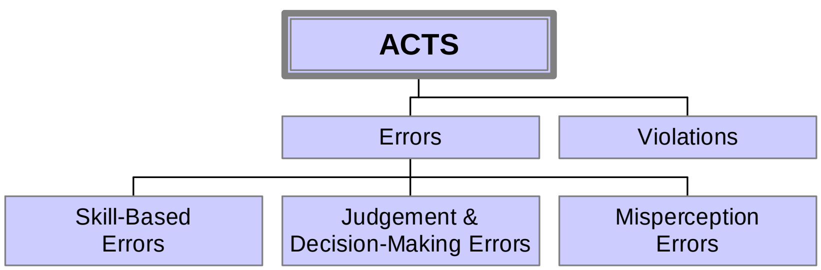


Figure 8. Categories of unsafe acts

2. Errors

Errors come in three forms: Skill-based, judgment and decision making, and perception. According to Shappell and Wiegmann, “errors represent the mental or physical activities of individuals that fail to achieve their intended outcome” (Shappell & Wiegmann, 2001, p. 62). Skill-based errors are generally fairly routine standard activities conducted by individuals. Such errors in skill include over-control, not following a checklist or procedure, and unintended operation of specific equipment. Errors in judgment and decision making involve choosing the wrong course of action in a given situation. These errors can take the form of rushing necessary actions, delaying a necessary action, or ignoring cautions or warning. Whatever form they take, these errors can nevertheless prove costly. Perception errors, or errors due to misperception, occur due to an incorrect response to an individual's senses.

Violations are the second form of unsafe acts and occur when rules are broken or instructions are not followed. Violations occur in the form of work-around violations, extreme or willful violations by an individual, or even widespread and routine violations (Naval Safety Center, 2007).

3. HFACS Application and Research

Since its creation, the HFACS taxonomy has been widely used, modified, and scrutinized. Due to the high cost of mishaps within industrial and commercial sectors, it makes sense for organizations to seek out a system, such as HFACS, to classify and count errors better for more effective prevention. However, one size does not often fit all. To this end, many researchers have adapted HFACS from its original form for use in areas, such as shipboard machinery spaces, the mining industry in Australia, and even a version for use with railroad error investigation. However, a fair number of skeptics remain who doubt the rating consistency (i.e., inter-rater reliability) when HFACS is used in mishap investigations.

More than 80 articles have been published on HFACS since its inception. The preponderance of this research presumes HFACS to be a valid, verified taxonomy, and use it as such. At the time of their paper in 2001, Shappell and Wiegmann cited inter-rater reliabilities from five studies with an average consensus of between .6 and .95 for a variety of studies. It should be noted that these studies were only coded at the categorical level, and not at a nano-code level (Shappell & Wiegmann, 2001).

With such claims of reliability, it is not surprising that many researchers accept HFACS at face value. Lenne and his colleagues' work with safety in the Australian mining community used the original 17 categories to code 263 mining incidents in Australia from 2007 to 2008 (Lenne, Salmon, Liu, & Trotter, 2011). This study used pairs of human factors researchers to translate codes from an Incident Cause Analysis Method (IDCAM) model into HFACS codes. Although the researchers coded independently, they resolved decision differences in a consensus method, much as a SIB would do (Lenne et al., 2011). Studies using methods such as these avoid the labor of calculating inter-rater reliability by ceding validity to the HFACS model.

In 2010, Wertheim used HFACS to look at human error in large-scale biometric systems. In this research, the use of HFACS was shown to improve fingerprint match rate by as much as 10%. Again, however, HFACS was assumed to be valid and no inter-rater reliability was not questioned (Wertheim, 2010).

Like Lenne et al. (2007), the Australian Transport Safety Bureau chose a similar path when examining accidents within the Australian civil aviation community in 2007. This study again coded accidents using pairs of raters. This consensus method is the most common method currently in use among users of HFACS according to the research available (Inglis, Sutton, & McRandle, 2007).

Over the years, new versions of HFACS have been developed. As the desire of organizations to narrow down and eliminate causal factors of accidents has increased, so has the specificity of HFACS. The preponderance of HFACS variants focus on developing systems at the categorical level, with only one version daring to venture into the nano-code level. Schroder-Hinrichs and his colleagues developed a version of HFACS for machinery spaces on commercial vessels. HFACS-MSS, as it is called, attempts to add specificity to the domain of machinery accidents on sea-going vessels. HFACS-MSS adds an additional category, outside factors, and changes some of the third tier categories from their original form in HFACS to increase specificity (Schroder-Hinrichs, Baldauf, & Ghirxi, 2011).

Similarly, Patterson and Shappell developed HFACS-MI for the Australian mining industry. This version, like that of Schroder-Hinrichs's, adds a fifth category of outside factors, which includes regulatory factors that may influence future mishaps (Patterson & Shappell, 2010).

In 2007, Reinach et al. (2007) took HFACS research a step further by both developing HFACS-RR for the Federal Railroad Administration and creating a software tool to perform much of the work. The Human Error Investigation Software Tool was created to effectively "do" HFACS. The program includes checklists, guides, a taxonomy, and definitions to assist raters in the process of error investigation and identification (Reinach, Viale, & Green, 2007).

Despite the bulk of HFACS research being generally positive, skeptics remain. It only makes sense that when working for organizations prepared to spend millions of dollars to reduce risk and mishaps that studies should focus on validating the method of risk identification actually being used.

O'Connor is perhaps the most well published skeptic of HFACS from an inter-rater perspective. He has published three papers examining the reliability of HFACS using trained raters and simulating mishap boards. O'Connor's findings demonstrate general unreliability in the usability of HFACS for several reasons. O'Connor cites training, experience, and format as possible issues with DoD HFACS (O'Connor, 2008; O'Connor, Walliser, & Philips, 2010; O'Connor & Walker, 2011).

In a study published in 2011, Wang et al. put HFACS to the test using air traffic controllers and human factors experts. Using 19 HFACS categories, the study showed agreement percentages below 40% for both groups just at the categorical level. No testing of nano-codes was conducted (Wang et al., 2011).

Lastly, in one of the few studies to attempt an adaptation or revision of HFACS at the nano-code level, Olsen and Shorrock found results similar to that of Wang et al. Their research showed inter-rater reliability at the categorical level to be under 50% (Olsen & Shorrock, 2010).

DoD HFACS is used throughout the U.S. military, as well as organizations around the world. It is not, however, a perfect system. Research continues to highlight the positive nature of HFACS, but also the negative issues associated with its use.

The largest strength of HFACS lies in its wide applicability and ability to be adapted to other uses. One of the best ways to determine the relative usefulness of any method is to test it against others that claim to accomplish a similar task. Salmon's research in 2012 compared HFACS with STAMP and Accimap, two other systems for error analysis. According to the study, HFACS "lends itself to multiple accident case analyses, and so is perhaps more suited to inclusion in safety management systems" (Salmon et al., 2012).

Based on the literature review, the largest strength of HFACS is perhaps also the greatest weakness of HFACS. As the system is rather generic, it lacks domain specificity, as pointed out by Salmon et al. and Griggs (Salmon et al., 2012, Griggs, 2012).

Additionally, while the system is adaptable and able to be transformed based on the requirements of the domain, such a process is difficult if the system has already been in place. Transforming the resulting codes from hundreds, perhaps thousands, of incidents for input into a database would require many man-years to re-read incident reports and re-classify each finding.

D. THE NEED FOR HFACS MARITIME (HFACS-M)

The generic nature of DoD HFACS as a one-size-fits-all model is insufficient for military components, nearly all of which have domain-specific factors associated with them. To improve reliability, the specificity of DoD HFACS must improve with regard to the surface Navy. To this end, a maritime version of HFACS, HFACS-M, was developed. This version will greatly serve the fleet by more accurately and efficiently identifying human error components in accident investigation. Additionally, a more fleet-centric version of HFACS will improve usability of HFACS and make it more suited for lower category mishaps. Finally, domain-specific terminology will reduce the training time required for novices to become familiar with HFACS.

The next chapter describes the development of HFACS-M and the method used to test DoD HFACS and HFACS-M.

THIS PAGE INTENTIONALLY LEFT BLANK

III. METHOD

A. RESEARCH APPROACH

This study sought to compare the inter-rater reliability among trained raters when using either HFACS or HFACS-M error classification taxonomy to code a mishap report. Subjects each received standardized training via a self-paced, pre-recorded, voice-over presentation, which provided familiarization with the respective taxonomy. Each subject next read through an executive summary of a report from the National Transportation Safety Board (NTSB). Subjects were asked to review the 11 findings associated with the mishap, and assign appropriate codes to each finding based on their understanding of the respective taxonomy. Analysis was then conducted to determine the inter-rater reliability within each of the two taxonomies, as well as the inter-rater reliability between SWOs and non-SWOs.

B. PARTICIPANTS

A total of 28 Naval Postgraduate School students, all U.S. military officers participated in this study. Gender and age were not determined to be a factor in the error classification process and were not recorded. Since DoD HFACS is intended for use by all branches of service, no service was excluded from participating in the study. Participants included members of the Army, Navy, Air Force, Marine Corps, and Coast Guard. Of these participants, five who took the case study using DoD HFACS had participated in accident investigations (two SWOs and three non-SWOs), and four participants (two SWOs and two non-SWOs) using HFACS-M (described in section C.3) had also participated in an accident investigation at some point in their careers. None who claimed to have participated in an accident investigation had any experience with HFACS in the course of those investigations. See Table 1.

Table 1. Two-by-two experiment matrix of participants by HFACS version

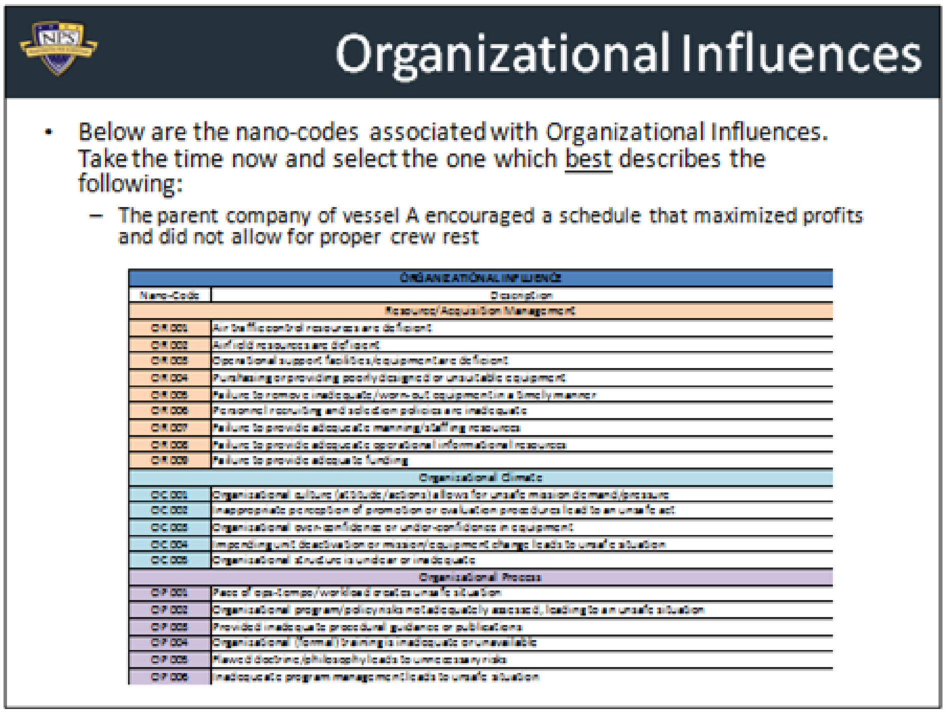
	DOD HFACS	HFACS-M
SWO	7	7
NON-SWO	7	7

C. APPARATUS

This study consisted of three major pieces: self-paced training, a case study, and the DoD HFACS and HFACS-M coding sheets.

1. Training

The training was conducted via a SAKAI site and featured a series of PowerPoint slides with associated voice recording. The presentation offered a brief history of either DoD HFACS or HFACS-M, as well as a description of the four categories of each of the taxonomies. The latter portion of the presentation featured a practice case study with four findings from a fictitious mishap. The training divided each of the four findings into its respective category based on the taxonomy being employed. Subjects were required to select the nano-code that best described the issue stated in the finding. The PowerPoint slides can be found in Appendix A. Figure 9 provides the reader with an example of one PowerPoint slide and its narration from the DoD HFACS training.



Below are the nano-codes associated with Organizational Influences. Take the time now and select the one which best describes the following:

The parent company of vessel A encouraged a schedule that did not allow for proper crew rest

Figure 9. Training slide example with speaker notes

2. Case Study

The second portion of the apparatus was the case study, which consisted of the executive summary of an actual mishap along with the findings from the mishap. The mishap was selected from the NTSB database based on its moderate number of findings and moderate level of complication. As the NTSB has consistent mishap investigation practices, it was determined that in the interest of time, it would be well suited for this study. The accident report used in this study was NTSB/MAR-11/04, Collision of Tankship *Eagle Otome* with Cargo Vessel *Gull Arrow* and Subsequent Collision with the *Dixie Vengeance* Tow. This incident occurred in the Sabine-Neches Canal, Port Arthur, Texas, on January 23, 2010. The executive summary reads as follows.

On Saturday, January 23, 2010, about 0935 central standard time, the 810-foot-long oil tankship *Eagle Otome* collided with the 597-foot-long general cargo vessel *Gull Arrow* at the Port of Port Arthur, Texas. A 297-foot-long barge, the *Kirby 30406*, which was being pushed by the towboat *Dixie Vengeance*, subsequently collided with the *Eagle Otome*. The tankship was inbound in the Sabine-Neches Canal with a load of crude oil en route to an ExxonMobil facility in Beaumont, Texas. Two pilots were on board, as called for by local waterway protocol. When the *Eagle Otome* approached the Port of Port Arthur, it experienced several unintended heading diversions culminating in the *Eagle Otome* striking the *Gull Arrow*, which was berthed at the port unloading cargo.

A short distance upriver from the collision site, the *Dixie Vengeance* was outbound with two barges. The towboat master saw the *Eagle Otome* move toward his side of the canal, and he put his engines full astern but could not avoid the subsequent collision. The *Kirby 30406*, which was the forward barge pushed by the *Dixie Vengeance*, collided with the *Eagle Otome* and breached the tankship's starboard ballast tank and the No. 1 center cargo tank a few feet above the waterline. As a result of the breach, 862,344 gallons of oil were released from the cargo tank, and an estimated 462,000 gallons of that amount spilled into the water. The three vessels remained together in the center of the canal while pollution response procedures were initiated. No crewmember on board any of the three vessels was injured.

The National Transportation Safety Board (NTSB) determines that the probable cause of the collision of tankship *Eagle Otome* with cargo vessel *Gull Arrow* and the subsequent collision with the *Dixie Vengeance* tow was the failure of the first pilot, who had navigational control of the *Eagle Otome*, to correct the sheering motions that began as a result of the late initiation of a turn at a mild bend in the waterway. Contributing to the accident was the first pilot's fatigue, caused by his untreated obstructive sleep apnea and his work schedule, which did not permit adequate sleep; his distraction from conducting a radio call, which the second pilot should have conducted in accordance with guidelines; and the lack of effective bridge resource management by both pilots. Also contributing was the lack of oversight by the Jefferson and Orange County Board of Pilot Commissioners.

Following the executive summary was a partial list of findings from the accident investigation presented to the participants. They read as follows.

> Based on your knowledge of the associated error classification taxonomy and your understanding of the facts surrounding the investigation, assign an appropriate nano-code that <u>best</u> describes each of the findings listed below. Please note that there is no right or wrong answer. Carefully read and consider the possible options before answering.
>
> 1. The *Eagle Otome* pilots did not follow Sabine Pilots Association guidelines with respect to division of duties while under way.
>
> 2. Although both pilots completed bridge resource management training, they failed to apply the team performance aspects of bridge resource management to this operation.
>
> 3. Contrary to pilot association guidelines, the first pilot on the Eagle Otome was conducting a radio call at a critical point in the waterway, and the radio call interfered with his ability to fully focus on conning the vessel.
>
> 4. Had the Eagle Otome pilots alerted the Dixie Vengeance master of the sheering problem, the force of the collision between the Eagle Otome and the Dixie Vengeance tow would have been lessened or the collision might have been avoided altogether.
>
> 5. The combination of untreated obstructive sleep apnea, disruption to his circadian rhythms, and extended periods of wakefulness that resulted from his work schedule caused the first pilot to be fatigued at the time of the accident.
>
> 6. The first pilot's failure to correct the sheering motions that began after his late turn initiation at Missouri Bend led to the accident.
>
> 7. The first pilot's fatigue adversely affected his ability to predict and stop the Eagle Otome's sheering.
>
> 8. No effective hours of service rules were in place that would have prevented the Sabine pilots from being fatigued by the schedules that they maintained.

9. The absence of an effective fatigue mitigation and prevention program among the pilots operating under the authority of the Jefferson and Orange County Board of Pilot Commissioners created a threat to the safety of the waterway, its users, and those nearby.

10. The Jefferson and Orange County Board of Pilot Commissioners should have more fully exercised its authority over pilot operations on the Sabine-Neches Waterway by becoming aware of and enforcing the Sabine Pilots Association's two-pilot guidelines and implementing a fatigue mitigation and prevention program among the Sabine pilots.

11. Commonly accepted human factors principles were not applied to the design of the Eagle Otome's engine control console, which increased the likelihood of error in the use of the controls.

The following findings from the mishap investigation were not presented to the participants because either they did not actually address an error or they speculated on or made recommendations for future improvements.

- Weather, mechanical failure, and illegal drug or alcohol use were not factors in the accident.
- The vessel meeting arrangement agreed to by the towboat master and the first pilot was appropriate and was not a factor in the accident.
- Personnel at Vessel Traffic Service Port Arthur played no role in the accident.
- The Coast Guard is the organization with the resources, capabilities, and expertise best suited to (1) enhance communication among pilot oversight organizations and (2) establish an easy-to-use and readily available database of pilot incidents and accidents.
- The first pilot's sounding the *Eagle Otome*'s whistle and the *Gull Arrow* master's sounding the cargo vessel's general alarm were prudent and effective.
- The accident response and oil spill recovery efforts were timely and effective.

- The dimensions of the Sabine-Neches Waterway may pose an unacceptable risk, given the size and number of vessels transiting the waterway.
- Consistent use of a vessel's name in radio communication can help avoid confusion and enhance bridge team coordination

3. DoD HFACS and HFACS-M

Participants received training on either DoD HFACS or HFACS-M, and received corresponding coding sheets. The categories, sub-codes, and nano-codes used in the DoD HFACS coding sheets were taken directly from the Naval Safety Center's 2007 booklet, "DoD Human Factors Analysis and Classification System (HFACS)."

The coding sheet was divided by category, sub-code, and nano-code as shown in Figure 10. Each nano-code was given its own row of 11 boxes representing the 11 findings of the accident investigation.

DOD HFACS		Findings										
Naval Safety Center, 2007 version		Mark an X in the box below associated with your choice for the best fit nanocode for each of the findings										
ACTS												
Nano-Code	Description											
Skill-Based Errors		1	2	3	4	5	6	7	8	9	10	11
AE 101	Unintended operation of equipment											
AE 102	Checklist not followed correctly											
AE 103	Procedure not followed correctly											
AE 104	Over-Controlled/under-controlled aircraft/vehicle											
AE 105	Breakdown in visual scan											
AE 106	Inadequate Anti-G straining maneuver											
Judgement and Decision-Making Errors												
AE 201	Inadequate real-time risk assessment (e.g., failure of time-critical ORM)											
AE 202	Failure to prioritize tasks adequately											
AE 203	Rushed a necessary action											
AE 204	Delayed a necessary action											
AE 205	Ignored a caution/warning											
AE 206	Wrong choice of action during an operation (e.g., response to an emergency)											
Perception Errors												
AE 301	Incorrect response to a misperception (e.g., visual illusion or spatial disorientation)											
Violations												
AV 001	Work-around violation (e.g., breaking the rules is prceived as the best solution)											
AV 002	Widespread/routine violation (e.g., habitual deviation from the rules that is tolerated by management)											
AV 003	Extreme violation (e.g., a violation not condoned by management											

Figure 10. DoD HFACS coding sheet example

HFACS-M was presented in the same manner as DoD HFACS. HFACS-M was created by modifying the original 2007 version of DoD HFACS to make it more specific to the surface Navy. To this end, the following modifications were made.

- AE102—Rephrased—Checklist not followed/not followed correctly
- AE 103—Rephrased—Procedure not followed/not followed correctly
- AE 104—Rephrased—Over-Controlled or under-controlled vessel
- AE 106—Removed (N/A for shipboard use)—Inadequate Anti-G straining maneuver
- PE 101—Rephrased—Icing/fog on window restricts visibility
- PE 102—Rephrased—Weather conditions restrict visibility
- PE 103—Rephrased—Vibrations/rolls affect vision or balance
- PE109—Rephrased—Backlighting/backscatter interfere with performance
- PE112—Added—High winds/Heavy seas affect/impair movement
- PE201—Removed (N/A for shipboard use)—Seat and restraint systems problems
- PE208—Added—Equipment not configured correctly
- PE209—Added—Corrective maintenance not conducted/not conducted correctly
- PE210—Added—Preventive maintenance not conducted/not conducted correctly
- PP101—Rephrased—Failure of watchteam/crew leadership
- PC301—Removed (N/A for shipboard use)—Effects of G forces (e.g., G-LOC)
- PC 304—Removed N/A parenthesis—Sudden incapacitation/unconsciousness (not due to G)
- PC 308—Rephrased—Circadian rhythm de-synchronization (watch rotation or shift work)
- PC 310—Removed (N/A for shipboard use)—Trapped gas disorders
- PC311—Removed (N/A for shipboard use)—Evolved gas disorders (e.g., decompression sickness/bends

Supervision—Renamed—Command

- SI007—Added—Failed to communicate intent (e.g., standing orders/night orders)

Manning/Personnel/Training Issues—Added new subcategory

- SP007—Added—Directed mission without sufficient manning
- SP007—Command (formal) training is inadequate
- SP008—Rephrased—Performed inadequate risk assessment (ORM)
- SV004—Moved to MPT sub-category
- OR001—Rephrased—Port facilities are deficient
- OR002—Channel markers/lighting are deficient
- OR005—Added—Failure to procure new systems/upgrades in a timely manner
- OP007—Organizational process provides inadequate, untimely guidance

These changes were necessary to remove ambiguity and to fill gaps in DoD HFACS because of the generic nature of the taxonomy.

The coding sheet for HFACS-M was also divided by category, sub-code, and nano-code as shown in Figure 11. Again, each nano-code was given its own row of 11 boxes representing the 11 findings of the accident investigation.

HFACS-M		Findings										
Naval Postgraduate School, 2013 version		Mark an X in the box below associated with your choice for the best fit nanocode for each of the findings										
ACTS												
Nano-Code	Description											
Skill-Based Errors		1	2	3	4	5	6	7	8	9	10	11
AE 101	Unintended operation of equipment											
AE 102	Checklist not followed/not followed correctly											
AE 103	Procedure not followed/not followed correctly											
AE 104	Over-Controlled or under-controlled vessel											
AE 105	Breakdown in visual scan											
Judgement and Decision-Making Errors												
AE 201	Inadequate real-time risk assessment (e.g., failure of time-critical ORM)											
AE 202	Failure to prioritize tasks adequately											
AE 203	Rushed a necessary action											
AE 204	Delayed a necessary action											
AE 205	Ignored a caution/warning											
AE 206	Wrong choice of action during an operation (e.g., response to an emergency)											
Perception Errors												
AE 301	Incorrect response to a misperception (e.g., visual illusion or spatial disorientation)											
Violations												
AV 001	Work-around violation (e.g., breaking the rules is prceived as the best solution)											
AV 002	Widespread/routine violation (e.g., habitual deviation from the rules that is tolerated by management)											
AV 003	Extreme violation (e.g., a violation not condoned by management											

Figure 11. HFACS-M coding sheet example

D. PROCEDURES

The Naval Postgraduate School's Institutional Review Board (IRB) reviewed and approved this research. Volunteers were recruited via email from the student body. They reported to the Human Systems Integration Laboratory and were met by the student researcher. They were asked to sit in front of a computer with either the DoD HFACS or HFACS-M training loaded on it. The subjects read and signed the informed consent form before proceeding. Next, each subject viewed the voice-recorded training slides. Subjects were instructed to progress through the slides at their own pace. Upon reaching the practice slides, subjects were instructed to read through all the possible nano-codes before making a selection. They were given a pen and scratch paper with which to take notes as desired.

Upon completion of the training, each subject was asked to answer the following questions.

1.	Have you completed the associated training?	Yes No
2.	Have you ever been involved in an accident investigation?	Yes No
3.	Have you ever used HFACS in the course of an accident investigation?	Yes No
4.	What is your current designator/MOS/AFSC?	______

Next, the subjects were instructed to read the executive summary from the NTSB accident report. Following this, they were given the list of 11 findings from the accident report and asked to assign one and only one nano-code from the taxonomy they were given that, in their judgment, best described the finding. Once the subjects finished marking all their selections, they were debriefed and thanked for their assistance.

E. DATA ANALYSIS

Upon completion of data collection, it was determined that no respondent data would be excluded. None of the subjects had used HFACS previously. Although several had been involved in accident investigations, it was determined by the research team that the experience did not give them any significant advantage.

The tables completed by individual raters were compiled into a data table. A Fleiss' Kappa analysis was conducted to determine the inter-rater reliability of those subjects using DoD HFACS compared to those who coded using HFACS-M. A Fleiss' Kappa analysis was also conducted to determine the inter-rater reliability between SWOs (maritime domain experts), and non-SWOs. These analyses were conducted at the categorical, sub-code, and nano-code levels. Fleiss' Kappa was used to determine inter-rater reliability among multiple raters, rather than Cohen's Kappa, which is designed for only two raters (Fleiss, 1971). Following the determination of Fleiss' Kappa for each data set, a simulation was conducted in R to determine the significance of the findings. See Fleiss (1971) for a description and explanation of Fleiss' Kappa.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. RESULTS

A. DESCRIPTION OF PARTICIPANTS

Twenty-eight Naval Postgraduate School students took part in this study. Subjects included members from each branch of service. Students self-identified their MOS/AFSC/Designator in the questionnaire provided. Table 1 shows the breakdown of participants. All told, 14 SWOs and 14 non-SWOS participated in the study. Participants were alternated between versions of HFACS.

B. NANO-CODE ANALYSIS

Each participant selected one nano-code from either DoD HFACS or HFACS-M for each of the 11 findings in the NTSB investigation. These selections were compiled into two tables, one for DoD HFACS and one for HFACS-M. Participants 1–7 of Table 2 and Table 3 were non-SWOs and participants 8–14 were SWOs.

Table 2. DoD HFACS results broken down by Designator/MOS/AFSC

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	AV001	PP103	AE202	PP106	PC307	AE104	PC307	OP003	OP006	OP002	PE204
2	1310	PP103	PP101	PC108	PP106	PC307	AE204	PC307	OP001	OC001	SI001	PP110
3	0602	AE103	AE103	AE206	PP106	PC307	AE206	PC307	SI004	SI004	SF001	PE204
4	7565	AE103	PP101	AE202	PP106	PC307	AE204	PC504	SV002	SI003	SF002	PE204
5	49A	PP103	OP004	PC102	PP106	PP205	PC504	PC404	OP002	OP003	SI004	PE206
6	21B/49	AE202	AV001	PC106	PP106	SI001	AE204	PP205	OR007	OP005	OP006	OR004
7	1810	PP103	PP101	PC106	PP106	PC307	AE103	AE201	OC001	SI004	SI001	PE204
8	1110	AE103	OP004	PC108	AE204	PC308	AE104	PC308	SI004	SF001	SF002	PE204
9	1110	SV001	AE103	AV001	AE206	OP001	AE206	OP001	OP002	OP005	OP002	OR004
10	1110	SV002	OP004	AE103	PP108	PC308	AE206	PC307	SI001	OP002	OP006	PE204
11	1110	AE103	PP103	PC106	PP106	PC308	AE206	OC001	OC001	OC001	OP005	PE204
12	1110	AV001	AE202	AE202	AE204	PC307	PP111	PP205	SI004	SF002	SI001	PE204
13	1110	AV003	PP101	AE206	PP106	PC305	AE104	PC307	OP002	OP003	OP006	PE204
14	1110	AE202	PP102	SF001	PP106	PP206	AE104	PC307	SF001	OP002	OP006	PE207

Table 3. HFACS-M results broken down by Designator/MOS/AFSC

HFACS-M		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	AE103	AE201	AE201	PP106	PC306	AE104	PC306	SI004	SF002	SI001	PE203
2	1810	AE103	PP112	PC106	PP106	PC304	AE204	PC306	SP201	OP006	OP002	PE203
3	0602	AV002	SI001	PC106	AE204	PC304	PC101	PP205	OP001	OP002	OP006	OR003
4	7523	AE201	AE103	PP108	AE206	PC307	AE204	PC306	PE204	PE202	SI001	OR004
5	1310	AE103	PP101	AE202	PP106	PC306	AE206	PC306	OP003	SI004	SI006	OR004
6	1120	AV001	PP102	AE203	PP106	OP001	AE206	PC505	OP001	OR007	OP006	PE206
7	19A	AV001	PP102	PP101	PP106	PC307	AE204	PC306	SF001	OP006	SV002	PE201
8	1110	AV001	PC206	PP103	PP106	PC304	AE204	PC307	PC307	OP002	OC001	PE201
9	1110	AE103	AE102	PC108	PP106	PC307	PP105	PC307	OP001	OP002	OP006	PE203
10	1110	AE103	PP101	PC108	PP106	PC306	AE104	PC510	SI004	SF002	SI001	PE208
11	1110	AV001	PC405	PC102	PP106	PC307	AE204	PC306	OP003	OP005	OC001	OR004
12	1110	AE103	AE206	AE206	AE204	OP001	AE204	PC306	OP003	OC001	OP007	PE203
13	1110	AE103	PP101	PC108	PP106	PC306	AE204	PC306	OP002	OP005	SI004	OP006
14	1110	PC306	PP101	PP108	PP106	PC306	AE204	PC307	OC001	SP007	SI001	OR004

1. DoD HFACS

From these results, tables were constructed to calculate Fleiss' Kappa. Table 4 shows an example. Each nano-code was assigned its own column and P_j, the proportion of assignments that were to the *j*-th category, was calculated for each. The rows delineate the finding with which the code is associated. In DoD HFACS, 147 possible nano-codes were available.

Table 4. DoD HFACS nano-code table example

DOD NANO	AE101	AE102	AE103	AE104	AE105	AE106
1	0	0	4	0	0	0
2	0	0	2	0	0	0
3	0	0	1	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	1	4	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
Total	0	0	8	4	0	0
Pj	0.000	0.000	0.052	0.026	0.000	0.000

Fleiss' Kappa was calculated to determine inter-rater reliability at the nano-code level for raters using DoD HFACS. Fleiss' Kappa was derived by first taking the difference of $\bar{P}$ and $\bar{P}e$ to find the degree above chance that was achieved. This difference is then divided by $1-\bar{P}e$ to obtain Fleiss' Kappa. The overall results were as follows: $\bar{P}$ = .185; $\bar{P}e$ = .036; K = .154.

The results were then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing DoD HFACS at the nano-code level, the results were as follows: $\bar{P}$ = .147; $\bar{P}e$ = .038;

K = .114. For non-SWOs employing DoD HFACS at the nano-code level, the results were as follows: $\overline{P}$ = .234; $\overline{P}e$ = .045; K = .198.

2. HFACS-M

Fleiss' Kappa was also calculated to determine inter-rater reliability at the nano-code level for raters using HFACS-M. In HFACS-M, 152 possible nano-codes were available. For HFACS-M at the nano-code level, the overall results were as follows: $\overline{P}$ = .212; $\overline{P}e$ = .037; K = .182.

The results were then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing HFACS-M at the nano-code level, the results were as follows: $\overline{P}$ = .238; $\overline{P}e$ = .046; K = .202 For non-SWOs employing HFACS-M at the nano-code level, the results were as follows: $\overline{P}$ = .169; $\overline{P}e$ = .037; K = .137.

C. SUB-CODE LEVEL

Each of the nano-codes in the DoD HFACS and HFACS-M taxonomies falls under a specific sub-code. For this next level of analysis, the nano-codes were translated into their respective sub-code within the original tables. Participants 1–7 of Table 5 and Table 6 were non-SWOs and participants 8–14 were SWOs.

Table 5. DoD HFACS sub-codes broken down by Designator/MOS/AFSC

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	A-V	P-CCPF	A-JDME	P-CCPF	P-APS	A-SB	P-APS	O-P	O-P	O-P	P-TE
2	1310	P-CCPF	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-C	S-IS	P-CCPF
3	0602	A-SB	A-SB	A-JDME	P-CCPF	P-APS	A-JDME	P-APS	S-IS	S-IS	S-FCKP	P-TE
4	7565	A-SB	P-CCPF	A-JDME	P-CCPF	P-APS	A-JDME	P-PF	S-SV	S-IS	S-FCKP	P-TE
5	49A	P-CCPF	O-P	P-AF	P-CCPF	P-SIS	P-PF	P-PML	O-P	O-P	S-IS	P-TE
6	21B/49	A-JDME	A-V	P-AF	P-CCPF	S-IS	A-JDME	P-SIS	O-RAM	O-P	O-P	O-RAM
7	1810	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-SB	A-JDME	O-C	S-IS	S-IS	P-TE
8	1110	A-SB	O-P	P-AF	A-JDME	P-APS	A-SB	P-APS	S-IS	S-FCKP	S-FCKP	P-TE
9	1110	S-SV	A-SB	A-V	A-JDME	O-P	A-JDME	O-P	O-P	O-P	O-P	O-RAM
10	1110	S-SV	O-P	A-SB	P-CCPF	P-APS	A-JDME	P-APS	S-IS	O-P	O-P	P-TE
11	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	O-C	O-C	O-C	O-P	P-TE
12	1110	A-V	A-JDME	A-JDME	A-JDME	P-APS	P-CCPF	P-SIS	S-IS	S-FCKP	S-IS	P-TE
13	1110	A-V	P-CCPF	A-JDME	P-CCPF	P-APS	A-SB	P-APS	O-P	O-P	O-P	P-TE
14	1110	A-JDME	P-CCPF	S-FCKP	P-CCPF	P-SIS	A-SB	P-APS	S-FCKP	O-P	O-P	P-TE

Table 6. HFACS-M sub-codes broken down by Designator/MOS/AFSC

HFACS-M												
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	A-SB	A-JDME	A-JDME	P-CCPF	P-APS	A-SB	P-APS	C-IS	C-FCKP	C-IS	P-TE
2	1810	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	C-PIO	O-P	O-P	P-TE
3	0602	A-V	C-IS	P-AF	A-JDME	P-APS	P-AF	P-SIS	O-P	O-P	O-P	O-RAM
4	7523	A-JDME	A-SB	P-CCPF	A-JDME	P-APS	A-JDME	P-APS	P-TE	P-TE	C-IS	O-RAM
5	1310	A-SB	P-CCPF	A-JDME	P-CCPF	P-APS	A-JDME	P-APS	O-P	C-IS	C-IS	O-RAM
6	1120	A-V	P-CCPF	A-JDME	P-CCPF	O-P	A-JDME	P-PF	O-P	O-RAM	O-P	P-TE
7	19A	A-V	P-CCPF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	C-FCKP	O-P	C-SV	P-TE
8	1110	A-V	P-PBF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	O-C	P-TE
9	1110	A-SB	A-SB	P-AF	P-CCPF	P-APS	P-CCPF	P-APS	O-P	O-P	O-P	P-TE
10	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-SB	P-PF	C-IS	C-FCKP	C-IS	P-TE
11	1110	A-V	P-PML	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	O-C	O-RAM
12	1110	A-SB	A-JDME	A-JDME	A-JDME	O-P	A-JDME	P-APS	O-P	O-C	O-P	P-TE
13	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	C-IS	O-P
14	1110	P-APS	P-CCPF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	O-C	C-MPT	C-IS	O-RAM

1. DoD HFACS

From these results, tables were constructed to calculate Fleiss' Kappa at the sub-code level. Each sub-code was once again assigned its own column and P_j was calculated for each. In DoD HFACS, 20 possible sub-codes were available. Table 7 shows the overall breakdown of sub-codes, shown in the columns, and findings, represented by the rows.

Table 7. Overall DoD HFACS sub-code table

DOD SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	S-IS	S-FCKP	S-PIO	S-SV	O-RAM	O-C	O-P	Pi
1	5	2	0	3	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0.176
2	2	1	0	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	3	0.275
3	1	5	0	1	0	0	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0.275
4	0	3	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0.637
5	0	0	0	0	0	0	2	0	0	0	0	0	10	1	0	0	0	0	0	1	0.505
6	5	7	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0.341
7	0	1	0	0	0	0	2	0	0	1	1	0	7	0	0	0	0	0	1	1	0.242
8	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	1	1	2	5	0.187
9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	2	7	0.286
10	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	7	0.330
11	0	0	0	0	0	11	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0.615
Total	13	19	0	5	0	11	4	22	6	1	2	0	17	12	7	0	3	3	5	24	3.868
Pj	0.084	0.123	0.000	0.032	0.000	0.071	0.026	0.143	0.039	0.006	0.013	0.000	0.110	0.078	0.045	0.000	0.019	0.019	0.032	0.156	

Fleiss' Kappa was calculated to determine inter-rater reliability at the sub-code level for raters using DoD HFACS. The results were as follows: $\bar{P}$ = .352; $\bar{P}e$ = .098; K = .281.

Table 7 was then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing DoD HFACS at the sub-code level, the results were as follows: $\bar{P}$ = .329; $\bar{P}e$ = .106; K = .250 For non-SWOs employing DoD HFACS at the sub-code level, the results were as follows: $\bar{P}$ = .364; $\bar{P}e$ = .099; K = .293.

2. HFACS-M

Fleiss' Kappa was also calculated to determine inter-rater reliability at the sub-code level for raters using HFACS-M. In HFACS-M, 21 possible sub-codes were available. Table 8 shows the overall breakdown of sub-codes, shown in the columns, and findings, represented by the rows.

Table 8. HFACS-M sub-code table

HFACS-M SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	C-IS	C-FCKP	C-MPT	C-PIO	C-SV	O-RAM	O-C	O-P	Pi
1	7	1	0	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.341
2	2	2	0	0	0	0	0	7	0	1	0	1	0	1	0	0	0	0	0	0	0	0.253
3	0	4	0	0	0	0	0	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0.297
4	0	3	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0.637
5	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	2	0.736
6	2	10	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.505
7	0	0	0	0	0	0	1	0	0	0	2	0	11	0	0	0	0	0	0	0	0	0.615
8	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	1	8	0.319
9	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	1	0	0	1	1	7	0.242
10	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0	2	5	0.286
11	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0.418
Total	11	20	0	5	0	10	1	23	7	1	2	1	24	10	3	1	1	1	6	4	23	4.648
Pj	0.071	0.130	0.000	0.032	0.000	0.065	0.006	0.149	0.045	0.006	0.013	0.006	0.156	0.065	0.019	0.006	0.006	0.006	0.039	0.026	0.149	

Fleiss' Kappa was calculated to determine inter-rater reliability at the sub-code level for raters using HFACS-M. The overall results were as follows: $\overline{P}$ = .423; $\overline{P}e$ = .105; K = .355.

Table 8 was then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing HFACS-M at the sub-code level, the results were as follows: $\overline{P}$ = .433; $\overline{P}e$ = .111; K = .362 For non-SWOs employing HFACS-M at the sub-code level, the results were as follows: $\overline{P}$ = .364; $\overline{P}e$ = .105; K = .289.

D. CATEGORICAL LEVEL

Each of the sub-codes in the DoD HFACS and HFACS-M taxonomies falls under a given category. For this next level of analysis, the sub-codes were translated into their respective category within the original tables. In DoD HFACS these categories consisted of organizational influences, supervision, preconditions, and acts. HFACS-M changes the supervision category to command. Participants 1–7 of Table 9 and Table 10 were non-SWOs and participants 8–14 were SWOs.

Table 9. DoD HFACS categories broken down by Designator/MOS/AFSC

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	A	P	A	P	P	A	P	O	O	O	P
2	1310	P	P	P	P	P	A	P	O	O	O	P
3	0602	A	A	A	P	P	A	P	O	O	O	P
4	7565	A	P	A	P	P	A	P	S	S	S	P
5	49A	P	O	P	P	P	P	P	O	O	S	P
6	21B/49	A	A	P	P	S	A	P	O	O	O	O
7	1810	A	P	P	P	P	A	A	O	S	S	P
8	1110	A	O	P	A	P	A	P	S	S	S	P
9	1110	S	A	A	A	O	A	O	O	O	O	O
10	1110	S	O	A	P	P	A	P	S	O	O	P
11	1110	A	P	P	P	P	A	O	O	O	O	P
12	1110	A	A	A	A	P	P	P	S	S	S	P
13	1110	A	P	A	P	P	A	P	O	O	O	P
14	1110	A	P	S	P	P	A	P	S	O	O	P

Table 10. HFACS-M categories broken down by Designator/MOS/AFSC

HFACS-M												
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	A	A	A	P	P	A	P	C	C	C	P
2	1810	A	A	P	P	P	A	P	C	O	O	P
3	0602	A	C	P	A	P	P	P	O	O	O	O
4	7523	A	A	P	A	P	A	P	P	P	C	O
5	1310	A	P	A	P	P	A	P	O	C	C	O
6	1120	A	P	A	P	O	A	P	O	O	O	P
7	19A	A	P	P	P	P	A	P	C	O	C	P
8	1110	A	P	P	P	P	A	P	O	O	O	P
9	1110	A	A	P	P	P	P	P	O	O	O	P
10	1110	A	A	P	P	P	A	P	C	C	C	P
11	1110	A	P	P	P	P	A	P	O	O	O	O
12	1110	A	A	A	A	O	A	P	O	O	O	P
13	1110	A	A	P	P	P	A	P	O	O	C	O
14	1110	P	P	P	P	P	A	P	O	C	C	O

1. DoD HFACS

From these results, tables were constructed to calculate Fleiss' Kappa. Each category was assigned its own column and P_j was calculated for each. Four possible categories were available in DoD HFACS. Table 11 shows the overall breakdown of categories, shown in the columns, and findings, represented by the rows.

Table 11. Overall DoD HFACS category table

DOD CAT	O	S	P	A	Pi
1	0	2	2	10	0.516
2	3	0	7	4	0.330
3	0	1	6	7	0.396
4	0	0	11	3	0.637
5	1	1	12	0	0.725
6	0	0	2	12	0.736
7	2	0	11	1	0.615
8	9	5	0	0	0.505
9	10	4	0	0	0.560
10	9	5	0	0	0.505
11	2	0	12	0	0.736
Total	36	18	63	37	6.264
Pj	0.234	0.117	0.409	0.240	

Fleiss' Kappa was calculated to determine inter-rater reliability at the categorical level for raters using DoD HFACS. The overall results were as follows: $\bar{P}$ = .569; $\bar{P}e$ = .293; K = .391.

Table 11 was then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing DoD HFACS at the category level, the results were as follows: $\bar{P}$ = .515; $\bar{P}e$ = .272; K = .334. For non-SWOs employing DoD HFACS at the category level, the results were as follows: $\bar{P}$ = .619; $\bar{P}e$ = .324; K = .436.

2. HFACS-M

Fleiss' Kappa was also calculated to determine inter-rater reliability at the categorical level for raters using HFACS-M. Four possible categories were available. Table 12 shows the overall breakdown of categories, shown in the columns, and findings, represented by the rows.

Table 12. HFACS-M category table

M CAT	O	C	P	A	Pi
1	0	0	1	13	0.857
2	0	1	6	7	0.396
3	0	0	10	4	0.560
4	0	0	11	3	0.637
5	2	0	12	0	0.736
6	0	0	2	12	0.736
7	0	0	14	0	1.000
8	9	4	1	0	0.462
9	9	4	1	0	0.462
10	7	7	0	0	0.462
11	6	0	8	0	0.473
Total	33	16	66	39	6.780
Pj	0.214	0.104	0.429	0.253	

Fleiss' Kappa was calculated to determine inter-rater reliability at the categorical level for raters using DoD HFACS. The overall results were as follows: $\bar{P}$ = .616; $\bar{P}e$ = .305; K = .448.

Table 12 was then divided between SWOs and non-SWOs. Fleiss' Kappa was calculated for each group individually. For SWOs employing HFACS-M at the category level, the results were as follows: $\bar{P}$ = .645; $\bar{P}e$ = .317; K = .481. For non-SWOs employing DoD HFACS at the category level, the results were as follows: $\bar{P}$ = .558; $\bar{P}e$ = .297; K = .372.

Table 13 shows a side-by-side comparison of Fleiss' Kappa for both HFACS versions at each of the three levels analyzed.

Table 13. Fleiss' Kappa comparison of DoD HFACS and HFACS-M results at all three levels

	Overall	SWO	NON-SWO
DOD HFACS (Nano-code)	0.154	0.114	0.198
HFACS-M (Nano-code)	0.182	0.202	0.137
DOD HFACS (Sub-code)	0.281	0.25	0.293
HFACS-M (Sub-code)	0.355	0.362	0.289
DOD HFACS (Category)	0.391	0.334	0.436
HFACS-M (Category)	0.448	0.481	0.372

The following chapter discusses the results of this analysis and their implications.

V. DISCUSSION

A. DISCUSSION

Accident investigations have concluded that virtually all major mishaps that occurred within the surface Navy are the product of human error (Lacy, 1998). To mitigate or prevent mishaps of this nature, it is vital that an appropriate method be established to categorize and count these errors. DoD HFACS is one method that has been employed for several years, but its reliability has been called into question on more than one occasion. To this end, a domain-specific version, HFACS-M, was developed and tested against the original version to assess the inter-rater reliability of each instrument.

B. RESEARCH QUESTIONS

The goal of this research was to determine if the perceived domain-specific gaps in DoD HFACS with respect to the surface Navy could be filled by creating a maritime specific version, HFACS-M. This study employed both HFACS taxonomies in conjunction with a case study to answer three questions.

1. Research Question #1

The first question addressed by this study is: Do SWOs and non-SWOs show the same consistency when applying DoD HFACS? HFACS was originally developed for application in naval aviation mishaps and has been amended and updated into its current version, DoD HFACS. The results of this study show a slightly higher Fleiss' Kappa for non-SWOs at every level (nano-code, sub-code, and category) using DoD HFACS, than for SWOs. Recall that Fleiss' Kappa is used to determine inter-rater reliability between a given number of raters. Fleiss' Kappa indicates agreement between raters over that which could be reached by chance (Fleiss, 1971). Fleiss' Kappa suffers from the fact that it does not have an agreed upon measure of significance, primarily because the number of subjects and categories directly impact the value (Gwet, 2010). Thus, it is not possible to assign a particular meaning to a score (good, fair, bad, etc.). However, it can be stated that the non-SWOs' higher scores when using DoD HFACS lead to the conclusion that a non-domain specific taxonomy yields a higher inter-rater reliability when employed with subjects not intimately familiar with the domain in question (maritime in this case). Again, based on the sample size and the fact that Fleiss' Kappa was used, it is not possible to say that the difference was statistically significant. However, it is clear that, in this particular study, non-SWOs were more consistent when using DoD HFACS. This conclusion supports the findings of Wang et al. (2001), in which research showed rater agreement below 40% at the categorical level. Like the 2001 study, this study found that the group of raters applying DoD HFACS had a Kappa of just .391, or 39 %. It is interesting to note that when this group was divided into SWOs and non-SWOs, the non-SWOs had an inter-reliability of .436, some 10% higher than SWOs and 4% higher than the group as a whole. Again, this result suggests that, when faced with a situation outside their scope of expertise (domain), subjects have a higher inter-rater reliability using a generic taxonomy.

2. Research Question #2

The second question addressed by this study is: What errors, overlaps, or gaps, if any, currently exist in DoD HFACS? Finding 7 from the NTSB accident report deals with the fatigue experienced by the pilot of one of the vessels involved. Nano-code PC307, Fatigue (sleep deprivation) was a commonly selected response, but PC308, Circadian rhythm de-synchronization, was also chosen by some subjects. PC308 seems to be a redundant code since a de-synchronization of an individual's circadian rhythm causes fatigue. Thus, are these overlaps within the taxonomy? The truth about overlaps in HFACS seems to be: It depends. It depends on the person doing the investigation and the person assigning the codes based on the finding of the investigation. The wording of the investigation can have considerable impact on which selection the rater makes. Likewise, the training of the rater, along with his or her background and expertise, all play pivotal roles in how the rater perceives the situation described in the investigation, and ultimately, which codes he or she will select.

Where gaps are concerned, DoD HFACS does seem to lack domain specificity, as asserted by Griggs (2012) and Salmon et al. (2012). Corrective and preventive maintenance issues are extremely important in all branches of service, yet are not a part of DoD HFACS. It should be noted, however, that it would be impossible to create appropriate nano-codes for every minor error. To this end, domain specificity should not focus simply on what is missing, but also what makes one domain different from the next (i.e., the difference between submarines and aircraft), as both can lead to the discovery of gaps.

Taking a broader look at DoD HFACS reveals an error classification taxonomy focused primarily on the event itself and not necessarily on latent errors. This emphasis on proximal errors rather than distal ones tends to eliminate potential latent errors from being identified. Manufacturing processes that produce hardware and software are less than perfect. Be it a mistake in a small string of code or a poorly welded seam, these errors can lie dormant for a large portion of the lifecycle of a ship, aircraft, or submarine until eventually the exact series of actions occur to cause them to be revealed in a catastrophic manner. Administrative processes that produce publications, instructions, and checklists are also prone to error. The incorrect wording of an emergent action in an instruction or the incorrect ordering of controlling actions for a casualty situation has the potential to cause more damage than they prevent. Issues such as these may be hard to identify during the course of an investigation and impossible to quantify without being properly addressed in the error classification instrument.

3. Research Question #3

The third question addressed by this study is: Does a tailored version of HFACS result in increased inter-rater reliability when classifying mishaps within the surface Navy? Why or why not? HFACS-M, the tailored maritime domain-specific version of DoD HFACS showed higher overall Fleiss' Kappa than DoD HFACS at every level of analysis (see Table 14). It is, however, not a staggering difference. HFACS-M had a higher inter-rater reliability at the categorical level by 5.7%, 7.4% at the sub-code level, and just 2.8% at the nano-code level. SWOs had a higher inter-rater reliability than non-SWOs when using HFACS-M at every level. In this study, SWOs had a higher inter-rater reliability than non-SWOs by 10.9% at the categorical level, 7.4% at the sub-code level, and 6.5% at the nano-code level when using HFACS-M. Fleiss' Kappa calculated for SWOs using HFACS-M were also higher than non-SWOs using DoD HFACS (by 4.5%, 6.9%, and .04% at the categorical, sub-code, and nano-code levels, respectively), which leads to the conclusion that subject matter experts (SWOs) have a slightly higher degree of agreement when using a domain specific instrument that employs terminology with which they are familiar. Based on the small sample size and untrained raters, however, further testing should be considered.

The conclusion that domain specific error taxonomies produce higher inter-rater reliability when employed by subject matter experts appears to support what Salmon et al. (2011) and Griggs (2012) assert, "the taxonomy needs to be relevant to the maritime community" (Griggs, 2012, p. 85). In this study, HFACS-M, a domain-specific instrument, resulted in a slightly greater overall inter-rater reliability than the more generic DoD HFACS.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This research provides support for what Griggs (2012) asserted; that domain-specific error classification taxonomies, when employed by experts in that domain, may have greater accuracy than a generic or non-specific version. Greater specificity in error classification leads to more accurate hazard identification, which reduces mishaps in both quantity and severity. This finding is important for the Navy and DoD as a whole as fiscal constraints set in and yard periods and dry dock availabilities become fewer and farther between.

It should be noted that the study was conducted with specific time constraints. The time to research and develop the apparatus and method spanned a six-month period. Although the subjects were experienced military officers, none had experience with HFACS outside of the brief training received immediately prior to reading the case study provided with this research. Despite these facts, it was still demonstrated that SWOs using HFACS-M displayed a slightly higher inter-rater reliability than non-SWOs. Fleiss' Kappa calculated for HFACS-M was also slightly higher than that of DoD HFACS.

B. RECOMMENDATIONS

Based on the results of this study, future research should address the addition of nano-codes to address the previously discussed latent errors to ensure a much more robust taxonomy. HFACS-M added several nano-codes having to do with maintenance processes. Currently, a large gap exists in DoD HFACS, but both versions would benefit from nano-codes designed to account for latent distal errors accurately. The development of such codes would require extensive study but would add significantly to the body of knowledge surrounding human error and its classification and quantification within the DoD.

The findings of this study support the need for domain-specific human error taxonomies. However, the field of human error would benefit from more extensive research. A study using trained raters and a Naval Safety Center (NAVSAFCEN) mishap investigation from the surface Navy could help to validate the HFACS-M taxonomy.

Finally, other domain-specific versions of HFACS should be developed and studied. To assume all branches of service and the communities therein have identical mishap potentials is to presume too much. The surface warfare community is far different from the aviation community, for example. While they can be generalized to a degree, at some point, the specific issues must be identified in the investigation process. These domain-specific issues can then be addressed so that the number of latent errors is reduced and the likelihood that an unfortunate chain of events will lead to a mishap is diminished.

APPENDIX A. HFACS TRAINING

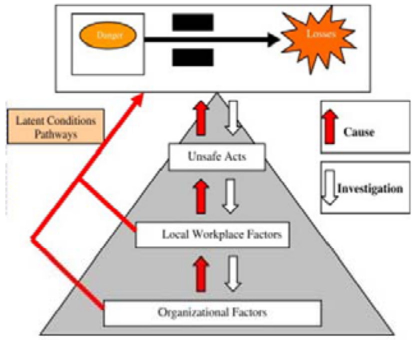
Human Error Classification Training

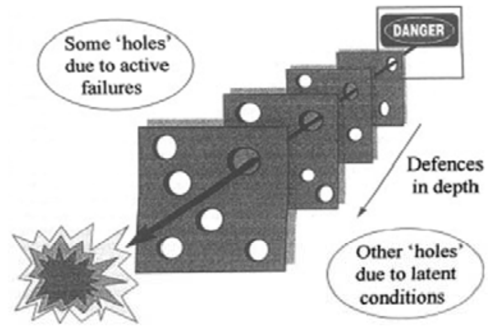
LT Jason Bilbro
Human Systems Integration
Naval Postgraduate School

Background

- Mishaps cost the Department of Defense billions each year
- Human error is involved in nearly every major mishap
- Mishap prevention first requires identification

Reason and the Swiss Cheese Model

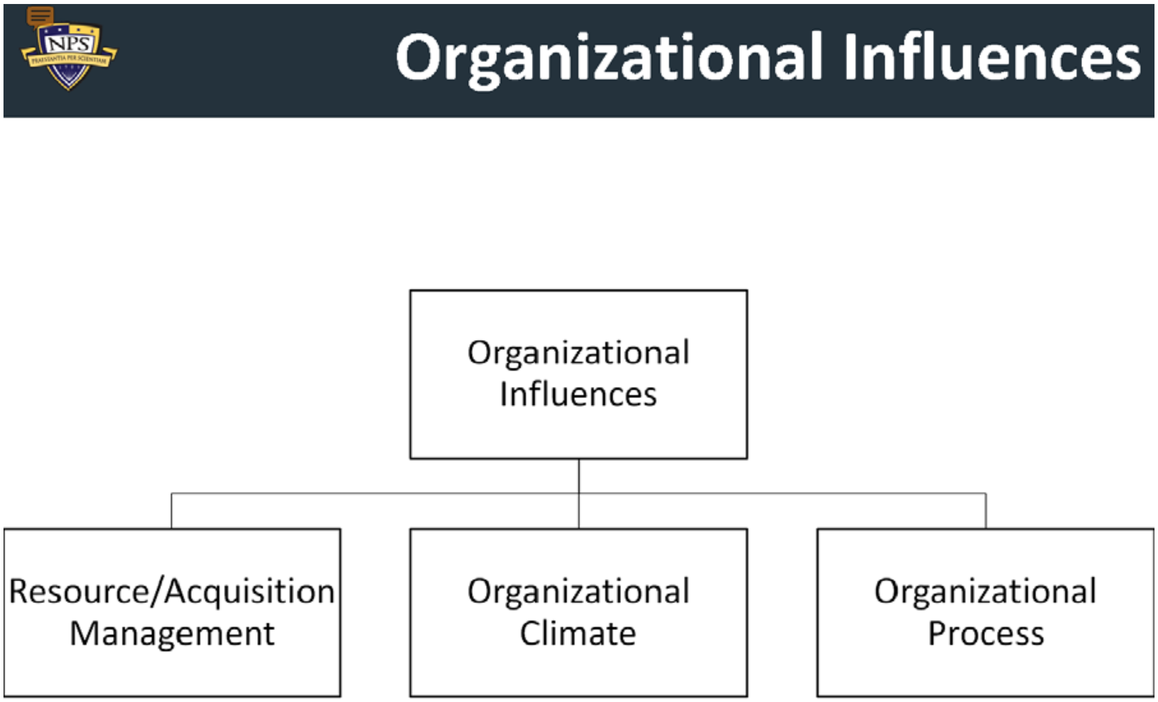


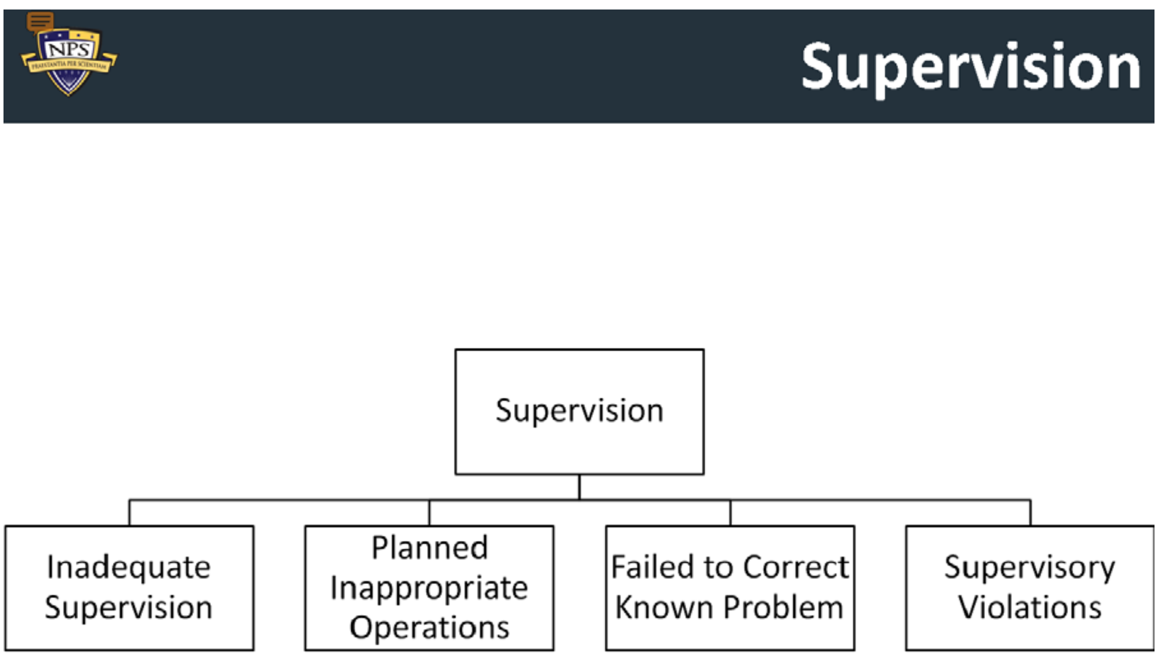


- Hazards find pathways through defenses and become losses
- Humans are not perfect and neither are our defenses or prevention measures

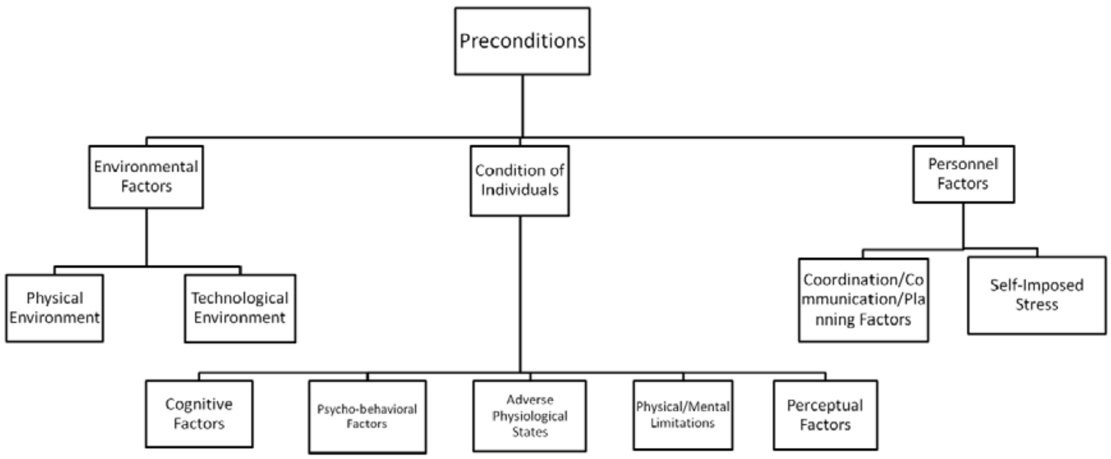
DOD HFACS

- Shappell and Weigmann created the HFACS taxonomy to turn theory into practice
- Four categories: Organizational Influences, Supervision, Precondition, Acts
- Each category is broken down into sub-codes with each sub-code into nano-codes

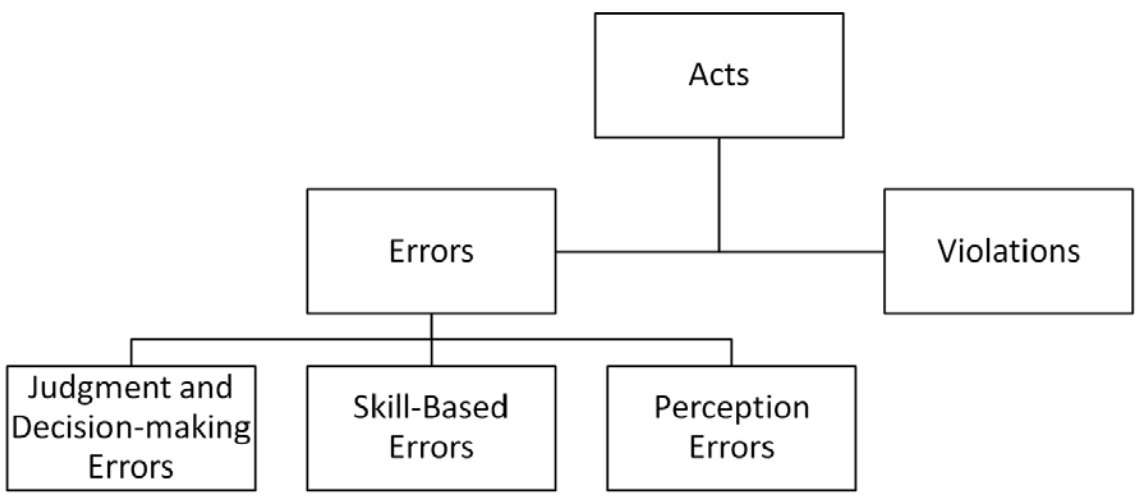

Organizational Influences
Organizational Influences
Resource/Acquisition Management
Organizational Climate
Organizational Process


Supervision
Supervision
Inadequate Supervision
Planned Inappropriate Operations
Failed to Correct Known Problem
Supervisory Violations

Preconditions



Acts



Example

- The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to watch rotation
- The parent company of vessel A encouraged a schedule that maximized profits and did not allow for proper crew rest
- The ship's master of vessel A routinely went without proper rest and did not encourage any different behavior among his crew
- The pilot of vessel B did not adjust course in a timely manner to avoid the collision.

Considerations

- Carefully consider which of the four levels applies.
  - The applicable sub-codes within each level will help guide the nano-code selection
    - Many nano-codes are similar. Pay attention to the context of the findings to select the best choice.

Organizational Influences

- Below are the nano-codes associated with Organizational Influences. Take the time now and select the one which <u>best</u> describes the following:
  – The parent company of vessel A encouraged a schedule that maximized profits and did not allow for proper crew rest

ORGANIZATIONAL INFLUENCE	
Nano-Code	Description
Resource/Acquisition Management	
OR 001	Air traffic control resources are deficient
OR 002	Airfield resources are deficient
OR 003	Operational support facilities/equipment are deficient
OR 004	Purshasing or providing poorly designed or unsuitable equipment
OR 005	Failure to remove inadequate/worn-out equipment in a timely manner
OR 006	Personnel recruiting and selection policies are inadequate
OR 007	Failure to provide adequeate manning/staffing resources
OR 008	Failure to provide adequeate operational informational resources
OR 009	Failure to provide adequate funding
Organizational Climate	
OC 001	Organizational culture (attitude/actions) allows for unsafe mission demand/pressure
OC 002	Inappropriate perception of promotion or evaluation procedures lead to an unsafe act
OC 003	Organizational over-confidence or under-confidence in equipment
OC 004	Impending unit deactivation or mission/equipment change leads to unsafe situation
OC 005	Organizational structure is unclear or inadequate
Organizational Process	
OP 001	Pace of ops-tempo/workload creates unsafe situation
OP 002	Organizational program/policy risks not adequately assessed, leading to an unsafe situation
OP 003	Provided inadequate procedural guidance or publications
OP 004	Organizational (formal) training is inadequate or unavailable
OP 005	Flawed doctrine/philosophy leads to unnecessary risks
OP 006	Inadequeate program management leads to unsafe situation

Organizational Influences (cont.)

- The best selection in this case is:
  – OC 001 Organizational culture (attitude/actions) allows for unsafe mission demand/pressure
- Alternative selections for this finding:

  OP 001 Pace of ops-tempo/workload creates unsafe situation is a tempting selection, but the issue at hand really speaks to an unsafe organizational climate that favors profits over safety.

Supervision

- Below are the nano-codes associated with Supervision. Take the time now and select the one which best describes the following
  - The ship's master of vessel A routinely went without proper rest and did not encourage any different behavior among his crew

SUPERVISION	
Nano-Code	Description
Inadequate Supervision	
SI 001	Command oversight inadequate
SI 002	Failed to ensure proper role-modeling
SI 003	Failed to provide proper training
SI 004	Failed to provide appropriate policy/guidance
SI 005	Personality conflict with supervisor
SI 006	Lack of supervisory responses to critical information
Failure to Correct Known Problem	
SF 001	Failed to identify/correct risky behavior
SF 002	Failed to correct unsafe practices
Planned Inappropriate Operations	
SP 001	Directed mission beyond personnel/equipment capabilities
SP 002	Personnel mismatch
SP 003	Selected individual with lack of current experience
SP 004	Selected individual with limited overall experience
SP 005	Selected individual with lack of proficiency
SP 006	Performed inadequate risk assessment
SP 007	Authorized unnecessary hazard
Supervisory Violations	
SV 001	Failure to enforce existing rules
SV 002	Allowing unwritten policies to become standard
SV 003	Directed individual to violate existing regulations
SV 004	Authorized unqualified individuals for mission

Supervision (cont.)

- The best selection in this case is:
  - SI 002 Failed to ensure proper role-modeling
- Alternative selections for this finding:
  - SF 001 Failed to identify/correct risky behavior and SF 002 Failed to correct unsafe practices are also reasonable selections, but the finding lends specifically to an issue with the way the ship's master allowed himself to be viewed and emulated.

Preconditions

- Below are the nano-codes associated with Preconditions. Take the time now and select the one which best describes the following:
  - The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to the watch rotation

PRECONDITIONS	
Nano-Code	Description
Physical Environment	
PE 101	Icing/fog on window restricts vision
PE 102	Weather conditions restricts vision
PE 103	Vibrations affect vision or balance
PE 104	Dust/smoke in workspace obstructs vision
PE 105	Windblast in workspace obstructs vision
PE 106	Cold stress
PE 107	Heat stress
PE 108	Extreme forces limit an individual's movement
PE 109	Lights of other vehicle/aircraft interfere with performance
PE 110	Noise
PE 111	Brownout (e.g., sand storm)/whiteout (e.g., snow storm)
Technological Environment	
SF 001	Seat and restraint systems problems
SF 002	Instrumentation and warning system issues
SF 003	Visibility restrictions (not weather related)
SF 004	Controls and switches are inadequate
SF 005	Automated system creates an unsafe situation
SF 006	Workspace incompatible with operation
SF 007	Personal equipment interference
SF 008	Communication equipment inadequate
Self-Imposed Stress	
PP 201	Physical fitness level (inappropriate for mission demands
PP 202	Alcohol
PP 203	Drugs/over-the-counter medication/supplements (not prescribed)
PP 204	Nutrition/diet
PP 205	Inadequate rest (self-imposed)
PP 206	Operating with known disqualifying medical condition

Coordination/Communication/Planning Factors	
PP 101	Failure of crew/team leadership
PP 102	Failure to cross-check/back-up
PP 103	Inadequate task delegation
PP 104	Rank/position intimidation
PP 105	Lack of assertiveness
PP 106	Critical information not commmunicated
PP 107	Standard/proper terminology not used
PP 108	Failure to ensure communicated intentions/actions were understood and follo
PP 109	Mission planning inadequate
PP 110	Mission briefing inadequate
PP 111	Failure to re-assess risk and adjust to changing circumstances
PP 112	Information is misinterpreted or disregarded
Awareness (Cognitive) Factors	
PC 101	Not paying attention
PC 102	Fixation ("channelized attention")
PC 103	Task over-saturation (e.g., too much information to process)
PC 104	Confusion
PC 105	Negative transfer (e.g., using old procedures for new system)
PC 106	Distraction
PC 107	Geographically lost (confusion about location)
PC 108	Interference/interruption during task
Physical/Mental Limitations	
PC 401	Learning rate limitations
PC 402	Memory limitations
PC 403	Body size/movement limitations
PC 404	Coordination deficiency
PC 405	Technical or procedural knowledge not retained after training

List of Preconditions continued on next page

Preconditions

- Below are the nano-codes associated with Preconditions. Take the time now and select the one that <u>best</u> describes the following:
  - The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to watch rotation

Perceptual Factors	
PC 501	Motion illusion
PC 502	Turning illusion/balance
PC 503	Visual illusion
PC 504	Misperception of changing environment
PC 505	Misinterpreted/misread instrument (e.g., misjudge altitude/distance/speed)
PC 506	Innacurate expectation (e.g., seeing/hearing what is expected instead of what is actually there/hear
PC 507	Misinterpretation of auditory cues
PC 508	Spatial disorientation - not recognized
PC 509	Spatial disorientation - recognized
PC 510	Spatial disorientation - incapacitating
PC 511	Time distortion
Psycho-Behavioral Factors	
PC 201	Pre-existing personality disorder (professionally diagnosed)
PC 202	Pre-existing psychological disorder (professionally diagnosed)
PC 203	Pre-existing psychosocial problem (professionally diagnosed)
PC 204	Emotional state
PC 205	Personality style
PC 206	Overconfidence
PC 207	Pressing (e.g., pushing self or equipment too hard)
PC 208	Complacency (e.g., absence of worry)
PC 209	Not enough motivation
PC 210	Misplaced motivation
PC 211	More aggressive than necessary
PC 212	Excessive motivation to succeed (e.g., "do or die")
PC 213	"Get-home-it-is"/"get-there-it-is"
PC 214	Inappropriate response due to expectation
PC 215	Motivational exhaustion ("burnout")

Adverse Psysiological Stress	
PC 301	Effects of G forces (e.g., G-LOC)
PC 302	Effects of prescribed drugs
PC 303	Operational injury/illness
PC 304	Sudden incapacitation/unconsciousness (not due to G)
PC 305	Pre-existing physical illness/injury
PC 306	Physical overexertion
PC 307	Fatigue (sleep deprivation)
PC 308	Circadian rhythm de-synchronization (e.g., jet lag or shift work)
PC 309	Motion sickness
PC 310	Trapped gas disorders
PC 311	Evolved gas disorders (e.g., decompression sickness/bends)
PC 312	Reduced oxygen (hypoxia)
PC 313	Hyperventilation (rapid breathing)
PC 314	Inadequate adaptation to darkness
PC 315	Dehydration
PC 316	Physical task over-saturation

Preconditions

- The best selection in this case is:
  - PC 307 Fatigue (sleep deprivation)
- Alternative selections for this finding:
  - PP 205 Inadequate rest (self-imposed) seems like a good choice, but it was the watch rotation that took its toll, not a direct decision by the First Mate
    - This finding deals directly with adverse physiological stress, in this case fatigue, experienced by the First Mate.

Acts

- Below are the nano-codes associated with Acts. Take the time now and select the one that <u>best</u> describes the following:
  - The pilot of vessel B did not adjust course in a timely manner to avoid the collision

ACTS	
Nano-Code	Description
Skill-Based Errors	
AE 101	Unintended operation of equipment
AE 102	Checklist not followed correctly
AE 103	Procedure not followed correctly
AE 104	Over-Controlled/under-controlled aircraft/vehicle
AE 105	Breakdown in visual scan
AE 106	Inadequate Anti-G straining maneuver
Judgement and Decision-Making Errors	
AE 201	Inadequate real-time risk assessment (e.g., failure of time-critical ORM)
AE 202	Failure to prioritize tasks adequately
AE 203	Rushed a necessary action
AE 204	Delayed a necessary action
AE 205	Ignored a caution/warning
AE 206	Wrong choice of action during an operation (e.g., response to an emergency)
Perception Errors	
AE 301	Incorrect response to a misperception (e.g., visual illusion or spatial disorientation)
Violations	
AV 001	Work-around violation (e.g., breaking the rules is prceived as the best solution)
AV 002	Widespread/routine violation (e.g., habitual deviation from the rules that is tolerated by managemer
AV 003	Extreme violation (e.g., a violation not condoned by management

Acts

- The best selection in this case is:
  - AE 204 Delayed a necessary action
    - This finding deals directly with judgment and decision-making. In this case, the failure of the pilot to act in a timely manner directly caused the mishap

Training Complete

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. HFACS-M TRAINING

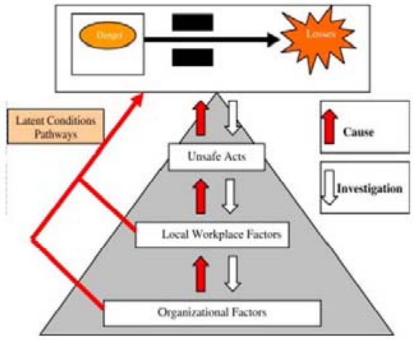
Human Error Classification Training

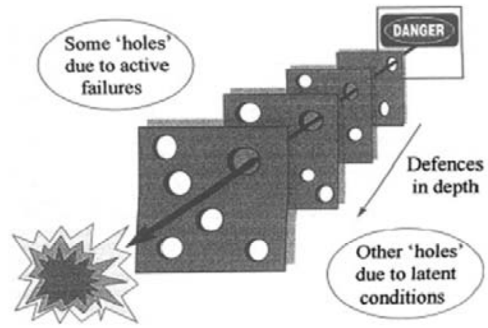
LT Jason Bilbro
Human Systems Integration
Naval Postgraduate School

Background

- Mishaps cost the Department of Defense billions each year
- Human error is involved in nearly every major mishap
- Mishap prevention first requires identification

Reason and the Swiss Cheese Model



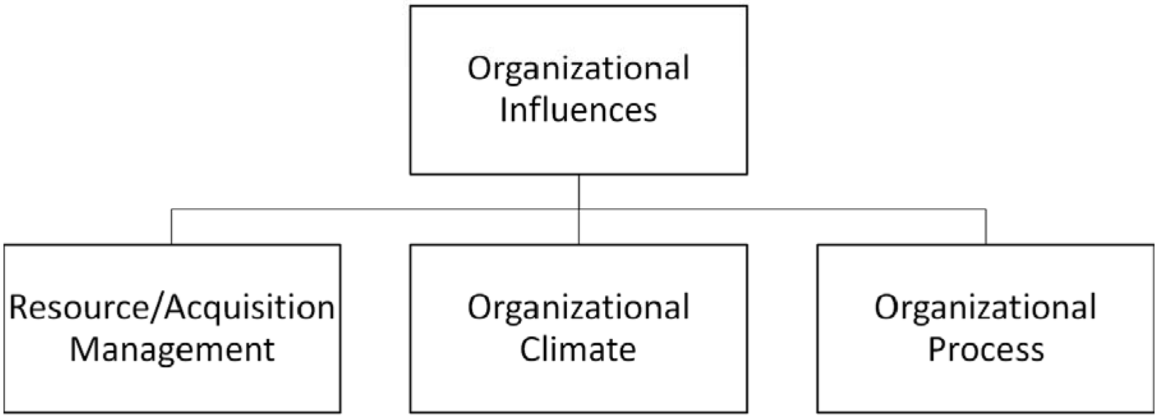


- Hazards find pathways through defenses and become losses
- Humans are not perfect and neither are our defenses or prevention measures

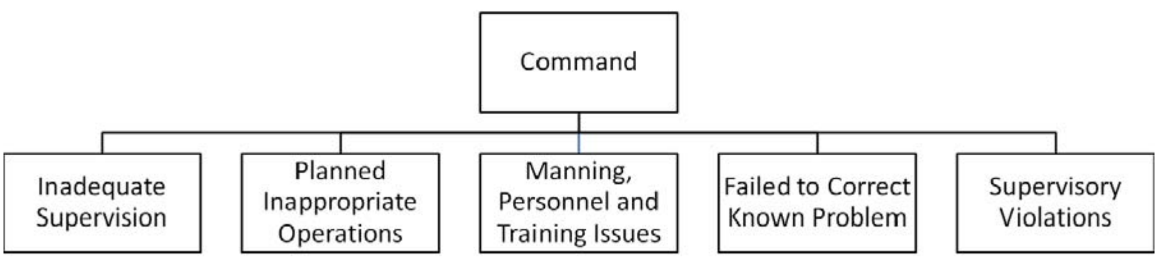
DOD HFACS

- Shappell and Weigmann created the HFACS taxonomy to turn theory into practice
- Each category is broken down into sub-codes with each sub-code into nano-codes
- HFACS-M looks at Organizational Influences, Command, Preconditions, and Acts

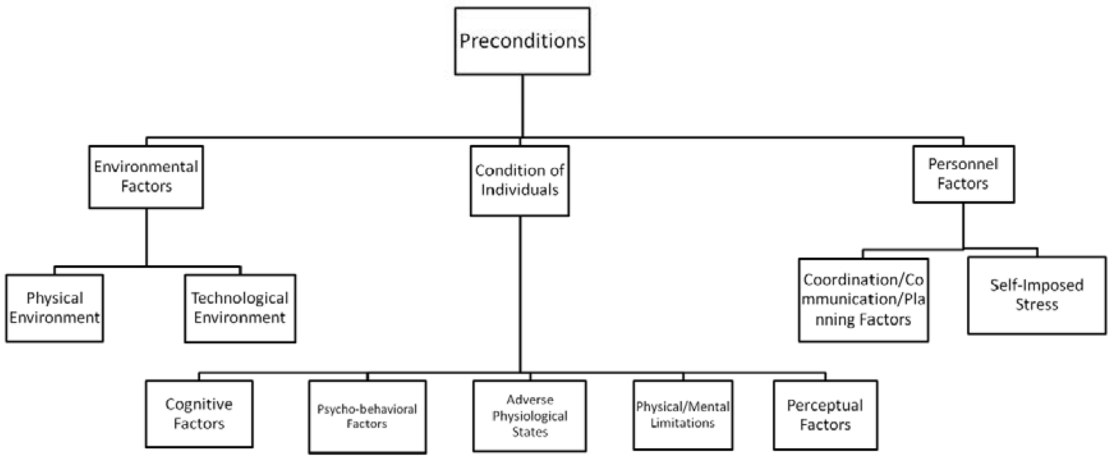
Organizational Influences



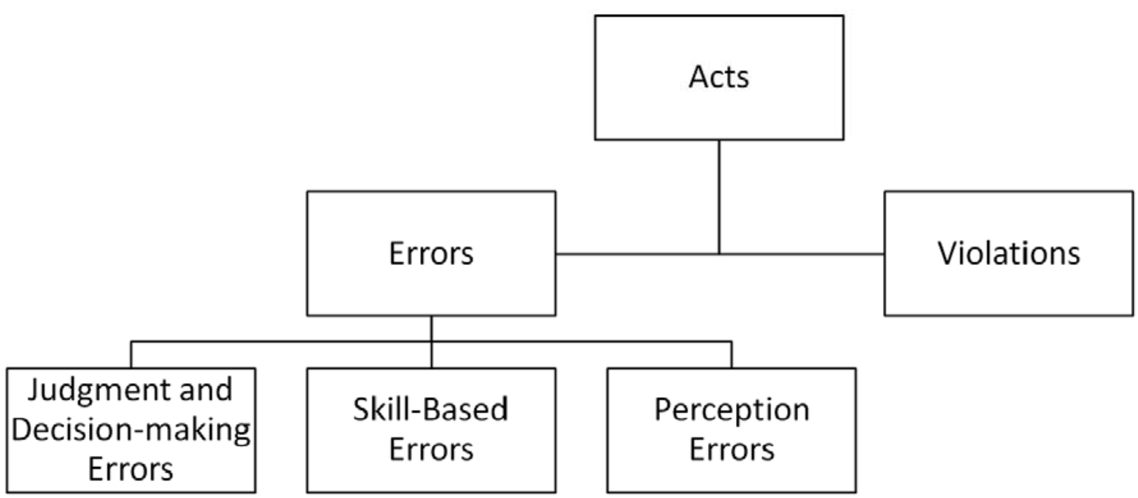
Command



Preconditions



Acts



Example

- The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to watch rotation
- The parent company of vessel A encouraged a schedule that maximized profits and did not allow for proper crew rest
- The ship's master of vessel A routinely went without proper rest and did not encourage any different behavior among his crew
- The pilot of vessel B did not adjust course in a timely manner to avoid the collision.

Considerations

- Carefully consider which of the four levels applies.
  - The applicable sub-codes within each level will help guide the nano-code selection
    - Many nano-codes are similar. Pay attention to the context of the findings to select the best choice.

Organizational Influences

- Below are the nano-codes associated with Organizational Influences. Take the time now and select the one which best describes the following:
  - The parent company of vessel A encouraged a schedule that maximized profits and did not allow for proper crew rest

ORGANIZATIONAL INFLUENCE	
Nano-Code	Description
Resource/Acquisition Management	
OR 001	Port facilities are deficient
OR 002	Channel markers/lighting are deficient
OR 003	Operational support facilities/equipment are deficient
OR 004	Purshasing or providing poorly designed or unsuitable equipment
OR 005	Failure to procure new systems/upgrades in a timely manner
OR 006	Failure to remove inadequate/worn-out equipment in a timely manner
OR 007	Personnel recruiting and selection policies are inadequate
OR 008	Failure to provide adequeate manning/staffing resources
OR 009	Failure to provide adequeate operational informational resources
OR 010	Failure to provide adequate funding
OR 011	Inadequate quality assurance within maintanance activity leads to unsafe situation
Organizational Climate	
OC 001	Organizational culture (attitude/actions) allows for unsafe mission demand/pressure
OC 002	Inappropriate perception of promotion or evaluation procedures lead to an unsafe act
OC 003	Organizational over-confidence or under-confidence in equipment
OC 004	Impending unit deactivation or mission/equipment change leads to unsafe situation
OC 005	Organizational structure is unclear or inadequate
Organizational Process	
OP 001	Pace of ops-tempo/workload creates unsafe situation
OP 002	Organizational program/policy risks not adequately assessed, leading to an unsafe situation
OP 003	Provided inadequate procedural guidance or publications
OP 004	Organizational (formal) training is inadequate or unavailable
OP 005	Flawed doctrine/philosophy leads to unnecessary risks
OP 006	Inadequeate program management leads to unsafe situation
OP 007	Organizational process provides inadequate, untimely guidance

Organizational Influences (cont.)

- The best selection in this case is:
  - OC 001 Organizational culture (attitude/actions) allows for unsafe mission demand/pressure
- Alternative selections for this finding:
  - OP 001 Pace of ops-tempo/workload creates unsafe situation is a tempting selection, but the issue at hand really speaks to an unsafe organizational climate that favors profits over safety.

Command

- Below are the nano-codes associated with Command. Take the time now and select the one which <u>best</u> describes the following
  - The ship's master of vessel A routinely went without proper rest and did not encourage any different behavior among his crew

COMMAND	
Nano-Code	Description
Inadequate Supervision	
CI 001	Inadequate oversight
CI 002	Failed to ensure proper role-modeling
CI 003	Failed to provide appropriate policy/guidance
CI 004	Personality conflict with supervisor
CI 005	Lack of supervisory responses to critical information
CI 006	Failed to communicate intent (e.g., standing orders/night orders)
Failure to Correct Known Problem	
CF 001	Failed to identify/correct risky behavior
CF 002	Failed to correct unsafe practices
Manning/Personnel/Training Issues	
CM 001	Directed mission beyond personnel/equipment capabilities
CM 002	Personnel mismatch
CM 003	Selected individual with lack of current experience
CM 004	Selected individual with limited overall experience
CM 005	Selected individual with lack of proficiency
CM 006	Directed mission without sufficient manning
CM 007	Command (formal) training inadequate
CM 008	Authorized unqualified individuals for mission
Planned Innappropriate Operations	
CP 001	Authorized unnecessary hazard
CP 002	Performed inadequate risk assessment (ORM)
Supervisory Violations	
CV 001	Failure to enforce existing rules
CV 002	Allowing unwritten policies to become standard
CV 003	Directed individual to violate existing regulations

Command (cont.)

- The best selection in this case is:
  - CI 002 Failed to ensure proper role-modeling
- Alternative selections for this finding:
  - CF 001 Failed to identify/correct risky behavior and CF 002 Failed to correct unsafe practices are also reasonable selections, but the finding lends specifically to an issue with the way the ship's master allowed himself to be viewed and emulated.

Preconditions

- Below are the nano-codes associated with Preconditions. Take the time now and select the one which <u>best</u> describes the following:
  - The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to the watch rotation

PRECONDITIONS	
Nano-Code	Description
Physical Environment	
PE 101	Icing/fog on window restricts visibililty
PE 102	Weather conditions restricts visibility
PE 103	Vibrations/rolls affect vision or balance
PE 104	Dust/smoke in workspace obstructs vision
PE 105	Windblast in workspace obstructs vision
PE 106	Cold stress
PE 107	Heat stress
PE 108	Extreme forces limit an individual's movement
PE 109	Backlighting/backscatter interfere with performance
PE 110	Noise
PE 111	Brownout (e.g., sand storm)/whiteout (e.g., snow storm)
PE 112	High winds/Heavy seas affect/impair movement
Technological Environment	
SF 001	Instrumentation and warning system issues
SF 002	Visibility restrictions (not weather related)
SF 003	Controls and switches are inadequate
SF 004	Automated system creates an unsafe situation
SF 005	Workspace incompatible with operation
SF 006	Personal equipment interference
SF 007	Communication equipment inadequate
SF 008	Equipment not configured correctly
SF 009	Corrective maintenance not conducted/not conducted correctly
SF 010	Preventative maintenance not conducted/not conducted correctly
Self-Imposed Stress	
PP 201	Physical fitness level (inappropriate for mission demands
PP 202	Alcohol
PP 203	Drugs/over-the-counter medication/supplements (not prescribed)
PP 204	Nutrition/diet
PP 205	Inadequate rest (self-imposed)
PP 206	Operating with known disqualifying medical condition

Coordination/Communication/Planning Factors	
PP 101	Failure of watchteam/crew leadership
PP 102	Failure to cross-check/back-up
PP 103	Inadequate task delegation
PP 104	Rank/position intimidation
PP 105	Lack of assertiveness
PP 106	Critical information not commmunicated
PP 107	Standard/proper terminology not used
PP 108	Failure to ensure communicated intentions/actions were understood and followed
PP 109	Mission planning inadequate
PP 110	Mission briefing inadequate
PP 111	Failure to re-assess risk and adjust to changing circumstances
PP 112	Information is misinterpreted or disregarded
Awareness (Cognitive) Factors	
PC 101	Not paying attention
PC 102	Fixation ("channelized attention")
PC 103	Task over-saturation (e.g., too much information to process)
PC 104	Confusion
PC 105	Negative transfer (e.g., using old procedures for new system)
PC 106	Distraction
PC 107	Geographically lost (confusion about location)
PC 108	Interference/interruption during task
Physical/Mental Limitations	
PC 401	Learning rate limitations
PC 402	Memory limitations
PC 403	Body size/movement limitations
PC 404	Coordination deficiency
PC 405	Technical or procedural knowledge not retained after training

List of Preconditions continued on next page

Preconditions

- Below are the nano-codes associated with Preconditions. Take the time now and select the one that best describes the following:
  - The pilot of vessel A, the First Mate, had only six hours of sleep in the previous 48 hours due to watch rotation

Perceptual Factors	
PC 501	Motion illusion
PC 502	Turning illusion/balance
PC 503	Visual illusion
PC 504	Misperception of changing environment
PC 505	Misinterpreted/misread instrument (e.g., misjudge altitude/distance/speed)
PC 506	Innacurate expectation (e.g., seeing/hearing what is expected instead of what is actually there/heard
PC 507	Misinterpretation of auditory cues
PC 508	Spatial disorientation - not recognized
PC 509	Spatial disorientation - recognized
PC 510	Spatial disorientation - incapacitating
PC 511	Time distortion
Psycho-Behavioral Factors	
PC 201	Pre-existing personality disorder (professionally diagnosed)
PC 202	Pre-existing psychological disorder (professionally diagnosed)
PC 203	Pre-existing psychosocial problem (professionally diagnosed)
PC 204	Emotional state
PC 205	Personality style
PC 206	Overconfidence
PC 207	Pressing (e.g., pushing self or equipment too hard)
PC 208	Complacency (e.g., absence of worry)
PC 209	Not enough motivation
PC 210	Misplaced motivation
PC 211	More aggressive than necessary
PC 212	Excessive motivation to succeed (e.g., "do or die")
PC 213	"Get-home-it-is"/"get-there-it-is"
PC 214	Inappropriate response due to expectation
PC 215	Motivational exhaustion ("burnout")

Adverse Psysiological Stress	
PC 301	Effects of prescribed drugs
PC 302	Operational injury/illness
PC 303	Sudden incapacitation/unconsciousness
PC 304	Pre-existing physical illness/injury
PC 305	Physical overexertion
PC 306	Fatigue (sleep deprivation)
PC 307	Circadian rhythm de-synchronization (watch rotation or shift work)
PC 308	Motion sickness
PC 309	Reduced oxygen (hypoxia)
PC 310	Hyperventilation (rapid breathing)
PC 311	Inadequate adaptation to darkness
PC 312	Dehydration
PC 313	Physical task over-saturation

Preconditions

- The best selection in this case is:
  - PC 306 Fatigue (sleep deprivation)
- Alternative selections for this finding:
  - PP 205 Inadequate rest (self-imposed) seems like a good choice, but it was the watch rotation that took its toll, not a direct decision by the First Mate
    - This finding deals directly with adverse physiological stress, in this case fatigue, experienced by the First Mate.

Acts

- Below are the nano-codes associated with Acts. Take the time now and select the one that <u>best</u> describes the following:
  - The pilot of vessel B did not adjust course in a timely manner to avoid the collision

ACTS	
Nano Code	Description
Skill-Based Errors	
AE 101	Unintended operation of equipment
AE 102	Checklist not followed/not followed correctly
AE 103	Procedure not followed/not followed correctly
AE 104	Over-Controlled or under-controlled vessel
AE 105	Breakdown in visual scan
Judgement and Decision-Making Errors	
AE 201	Inadequate real-time risk assessment (e.g., failure of time-critical ORM)
AE 202	Failure to prioritize tasks adequately
AE 203	Rushed a necessary action
AE 204	Delayed a necessary action
AE 205	Ignored a caution/warning
AE 206	Wrong choice of action during an operation (e.g., response to an emergency)
Perception Errors	
AE 301	Incorrect response to a misperception (e.g., visual illusion or spatial disorientation)
Violations	
AV 001	Work-around violation (e.g., breaking the rules is prceived as the best solution)
AV 002	Widespread/routine violation (e.g., habitual deviation from the rules that is tolerated by management)
AV 003	Extreme violation (e.g., a violation not condoned by management

Acts

- The best selection in this case is:
  - AE 204 Delayed a necessary action
    - This finding deals directly with judgment and decision-making. In this case, the failure of the pilot to act in a timely manner directly caused the mishap

Training Complete

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. HFACS (EXCEL)

Perceptual Factors		1	2	3	4	5	6	7	8	9	10	11
PC 501	Motion illusion											
PC 502	Turning illusion/balance											
PC 503	Visual illusion											
PC 504	Misperception of changing environment											
PC 505	Misinterpreted/misread instrument (e.g., misjudge altitude/distance/speed)											
PC 506	Innacurate expectation (e.g., seeing/hearing what is expected instead of what is actually there/heard)											
PC 507	Misinterpretation of auditory cues											
PC 508	Spatial disorientation - not recognized											
PC 509	Spatial disorientation - recognized											
PC 510	Spatial disorientation - incapacitating											
PC 511	Time distortion											
Psycho-Behavioral Factors												
PC 201	Pre-existing personality disorder (professionally diagnosed)											
PC 202	Pre-existing psychological disorder (professionally diagnosed)											
PC 203	Pre-existing psychosocial problem (professionally diagnosed)											
PC 204	Emotional state											
PC 205	Personality style											
PC 206	Overconfidence											
PC 207	Pressing (e.g., pushing self or equipment too hard)											
PC 208	Complacency (e.g., absence of worry)											
PC 209	Not enough motivation											
PC 210	Misplaced motivation											
PC 211	More aggressive than necessary											
PC 212	Excessive motivation to succeed (e.g., "do or die")											
PC 213	"Get-home-it-is"/"get-there-it-is"											
PC 214	Inappropriate response due to expectation											
PC 215	Motivational exhaustion ("burnout")											
Adverse Psysiological Stress												
PC 301	Effects of G forces (e.g., G-LOC)											
PC 302	Effects of prescribed drugs											
PC 303	Operational injury/illness											
PC 304	Sudden incapacitation/unconsciousness (not due to G)											
PC 305	Pre-existing physical illness/injury											
PC 306	Physical overexertion											
PC 307	Fatigue (sleep deprivation)											
PC 308	Circadian rhythm de-synchronization (e.g., jet lag or shift work)											
PC 309	Motion sickness											
PC 310	Trapped gas disorders											
PC 311	Evolved gas disorders (e.g., decompression sickness/bends)											
PC 312	Reduced oxygen (hypoxia)											
PC 313	Hyperventilation (rapid breathing)											
PC 314	Inadequate adaptation to darkness											
PC 315	Dehydration											
PC 316	Physical task over-saturation											
SUPERVISION												
Nano-Code	Description											
Inadequate Supervision												
SI 001	Command oversight inadequate											
SI 002	Failed to ensure proper role-modeling											
SI 003	Failed to provide proper training											
SI 004	Failed to provide appropriate policy/guidance											
SI 005	Personality conflict with supervisor											
SI 006	Lack of supervisory responses to critical information											
Failure to Correct Known Problem												
SF 001	Failed to identify/correct risky behavior											
SF 002	Failed to correct unsafe practices											
Planned Inappropriate Operations												
SP 001	Directed mission beyond personnel/equipment capabilities											
SP 002	Personnel mismatch											
SP 003	Selected individual with lack of current experience											
SP 004	Selected individual with limited overall experience											
SP 005	Selected individual with lack of proficiency											
SP 006	Performed inadequate risk assessment											
SP 007	Authorized unnecessary hazard											
Supervisory Violations												
SV 001	Failure to enforce existing rules											
SV 002	Allowing unwritten policies to become standard											
SV 003	Directed individual to violate existing regulations											
SV 004	Authorized unqualified individuals for mission											
ORGANIZATIONAL INFLUENCE												
Nano-Code	Description											
Resource/Acquisition Management												
OR 001	Air traffic control resources are deficient											
OR 002	Airfield resources are deficient											
OR 003	Operational support facilities/equipment are deficient											
OR 004	Purchasing or providing poorly designed or unsuitable equipment											
OR 005	Failure to remove inadequate/worn-out equipment in a timely manner											
OR 006	Personnel recruiting and selection policies are inadequate											
OR 007	Failure to provide adequeate manning/staffing resources											
OR 008	Failure to provide adequeate operational informational resources											
OR 009	Failure to provide adequate funding											
Organizational Climate												
OC 001	Organizational culture (attitude/actions) allows for unsafe mission demand/pressure											
OC 002	Inappropriate perception of promotion or evaluation procedures lead to an unsafe act											
OC 003	Organizational over-confidence or under-confidence in equipment											
OC 004	Impending unit deactivation or mission/equipment change leads to unsafe situation											
OC 005	Organizational structure is unclear or inadequate											
Organizational Process												
OP 001	Pace of ops-tempo/workload creates unsafe situation											
OP 002	Organizational program/policy risks not adequately assessed, leading to an unsafe situation											
OP 003	Provided inadequate procedural guidance or publications											
OP 004	Organizational (formal) training is inadequate or unavailable											
OP 005	Flawed doctrine/philosophy leads to unnecessary risks											
OP 006	Inadequeate program management leads to unsafe situation											

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX D. HFACS-M (EXCEL)

	Perceptual Factors	1	2	3	4	5	6	7	8	9	10	11
PC 501	Motion illusion											
PC 502	Turning illusion/balance											
PC 503	Visual illusion											
PC 504	Misperception of changing environment											
PC 505	Misinterpreted/misread instrument (e.g., misjudge altitude/distance/speed)											
PC 506	Innacurate expectation (e.g., seeing/hearing what is expected instead of what is actually there/heard)											
PC 507	Misinterpretation of auditory cues											
PC 508	Spatial disorientation - not recognized											
PC 509	Spatial disorientation - recognized											
PC 510	Spatial disorientation - incapacitating											
PC 511	Time distortion											
	Psycho-Behavioral Factors											
PC 201	Pre-existing personality disorder (professionally diagnosed)											
PC 202	Pre-existing psychological disorder (professionally diagnosed)											
PC 203	Pre-existing psychosocial problem (professionally diagnosed)											
PC 204	Emotional state											
PC 205	Personality style											
PC 206	Overconfidence											
PC 207	Pressing (e.g., pushing self or equipment too hard)											
PC 208	Complacency (e.g., absence of worry)											
PC 209	Not enough motivation											
PC 210	Misplaced motivation											
PC 211	More aggressive than necessary											
PC 212	Excessive motivation to succeed (e.g., "do or die")											
PC 213	"Get-home-it-is"/"get-there-it-is"											
PC 214	Inappropriate response due to expectation											
PC 215	Motivational exhaustion ("burnout")											
	Adverse Psysiological Stress											
PC 301	Effects of prescribed drugs											
PC 302	Operational injury/illness											
PC 303	Sudden incapacitation/unconsciousness											
PC 304	Pre-existing physical illness/injury											
PC 305	Physical overexertion											
PC 306	Fatigue (sleep deprivation)											
PC 307	Circadian rhythm de-synchronization (watch rotation or shift work)											
PC 308	Motion sickness											
PC 311	Reduced oxygen (hypoxia)											
PC 312	Hyperventilation (rapid breathing)											
PC 313	Inadequate adaptation to darkness											
PC 314	Dehydration											
PC 315	Physical task over-saturation											
	COMMAND											
Nano-Code	Description											
	Inadequate Supervision											
SI 001	Inadequate oversight											
SI 002	Failed to ensure proper role-modeling											
SI 003	Failed to provide proper training											
SI 004	Failed to provide appropriate policy/guidance											
SI 005	Personality conflict with supervisor											
SI 006	Lack of supervisory responses to critical information											
SI 007	Failed to communicate intent (e.g., standing orders/night orders)											
	Failure to Correct Known Problem											
SF 001	Failed to identify/correct risky behavior											
SF 002	Failed to correct unsafe practices											
	Manning/Personnel/Training Issues											
SP 001	Directed mission beyond personnel/equipment capabilities											
SP 002	Personnel mismatch											
SP 003	Selected individual with lack of current experience											
SP 004	Selected individual with limited overall experience											
SP 005	Selected individual with lack of proficiency											
SP 006	Directed mission without sufficient manning											
SP 007	Command (formal) training inadequate											
SP 008	Authorized unqualified individuals for mission											
	Planned Innappropriate Operations											
SP 101	Authorized unnecessary hazard											
SP 102	Performed inadequate risk assessment (ORM)											
	Supervisory Violations											
SV 001	Failure to enforce existing rules											
SV 002	Allowing unwritten policies to become standard											
SV 003	Directed individual to violate existing regulations											
	ORGANIZATIONAL INFLUENCE											
Nano-Code	Description											
	Resource/Acquisition Management											
OR 001	Port facilities are deficient											
OR 002	Channel markers/lighting are deficient											
OR 003	Operational support facilities/equipment are deficient											
OR 004	Purchasing or providing poorly designed or unsuitable equipment											
OR 010	Failure to procure new systems/upgrades in a timely manner											
OR 005	Failure to remove inadequate/worn-out equipment in a timely manner											
OR 006	Personnel recruiting and selection policies are inadequate											
OR 007	Failure to provide adequeate manning/staffing resources											
OR 008	Failure to provide adequeate operational informational resources											
OR 009	Failure to provide adequate funding											
OR 010	Inadequate quality assurance within maintanance activity leads to unsafe situation											
	Organizational Climate											
OC 001	Organizational culture (attitude/actions) allows for unsafe mission demand/pressure											
OC 002	Inappropriate perception of promotion or evaluation procedures lead to an unsafe act											
OC 003	Organizational over-confidence or under-confidence in equipment											
OC 004	Impending unit deactivation or mission/equipment change leads to unsafe situation											
OC 005	Organizational structure is unclear or inadequate											
	Organizational Process											
OP 001	Pace of ops-tempo/workload creates unsafe situation											
OP 002	Organizational program/policy risks not adequately assessed, leading to an unsafe situation											
OP 003	Provided inadequate procedural guidance or publications											
OP 004	Organizational (formal) training is inadequate or unavailable											
OP 005	Flawed doctrine/philosophy leads to unnecessary risks											
OP 006	Inadequeate program management leads to unsafe situation											
OP 007	Organizational process provides inadequate, untimely guidance											

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX E. THESIS DATA

A. NANO CODE

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	AV001	PP103	AE202	PP106	PC307	AE104	PC307	OP003	OP006	OP002	PE204
2	1310	PP103	PP101	PC108	PP106	PC307	AE204	PC307	OP001	OC001	SI001	PP110
3	0602	AE103	AE103	AE206	PP106	PC307	AE206	PC307	SI004	SI004	SF001	PE204
4	7565	AE103	PP101	AE202	PP106	PC307	AE204	PC504	SV002	SI003	SF002	PE204
5	49A	PP103	OP004	PC102	PP106	PP205	PC504	PC404	OP002	OP003	SI004	PE206
6	21B/49	AE202	AV001	PC106	PP106	SI001	AE204	PP205	OR007	OP005	OP006	OR004
7	1810	PP103	PP101	PC106	PP106	PC307	AE103	AE201	OC001	SI004	SI001	PE204
8	1110	AE103	OP004	PC108	AE204	PC308	AE104	PC308	SI004	SF001	SF002	PE204
9	1110	SV001	AE103	AV001	AE206	OP001	AE206	OP001	OP002	OP005	OP002	OR004
10	1110	SV002	OP004	AE103	PP108	PC308	AE206	PC307	SI001	OP002	OP006	PE204
11	1110	AE103	PP103	PC106	PP106	PC308	AE206	OC001	OC001	OC001	OP005	PE204
12	1110	AV001	AE202	AE202	AE204	PC307	PP111	PP205	SI004	SF002	SI001	PE204
13	1110	AV003	PP101	AE206	PP106	PC305	AE104	PC307	OP002	OP003	OP006	PE204
14	1110	AE202	PP102	SF001	PP106	PP206	AE104	PC307	SF001	OP002	OP006	PE207

HFACS-M		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	AE103	AE201	AE201	PP106	PC306	AE104	PC306	SI004	SF002	SI001	PE203
2	1810	AE103	PP112	PC106	PP106	PC304	AE204	PC306	SP201	OP006	OP002	PE203
3	0602	AV002	SI001	PC106	AE204	PC304	PC101	PP205	OP001	OP002	OP006	OR003
4	7523	AE201	AE103	PP108	AE206	PC307	AE204	PC306	PE204	PE202	SI001	OR004
5	1310	AE103	PP101	AE202	PP106	PC306	AE206	PC306	OP003	SI004	SI006	OR004
6	1120	AV001	PP102	AE203	PP106	OP001	AE206	PC505	OP001	OR007	OP006	PE206
7	19A	AV001	PP102	PP101	PP106	PC307	AE204	PC306	SF001	OP006	SV002	PE201
8	1110	AV001	PC206	PP103	PP106	PC304	AE204	PC307	PC307	OP002	OC001	PE201
9	1110	AE103	AE102	PC108	PP106	PC307	PP105	PC307	OP001	OP002	OP006	PE203
10	1110	AE103	PP101	PC108	PP106	PC306	AE104	PC510	SI004	SF002	SI001	PE208
11	1110	AV001	PC405	PC102	PP106	PC307	AE204	PC306	OP003	OP005	OC001	OR004
12	1110	AE103	AE206	AE206	AE204	OP001	AE204	PC306	OP003	OC001	OP007	PE203
13	1110	AE103	PP101	PC108	PP106	PC306	AE204	PC306	OP002	OP005	SI004	OP006
14	1110	PC306	PP101	PP108	PP106	PC306	AE204	PC307	OC001	SP007	SI001	OR004

B. SUB CODE

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	A-V	P-CCPF	A-JDME	P-CCPF	P-APS	A-SB	P-APS	O-P	O-P	O-P	P-TE
2	1310	P-CCPF	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-C	S-IS	P-CCPF
3	0602	A-SB	A-SB	A-JDME	P-CCPF	P-APS	A-JDME	P-APS	S-IS	S-IS	S-FCKP	P-TE
4	7565	A-SB	P-CCPF	A-JDME	P-CCPF	P-APS	A-JDME	P-PF	S-SV	S-IS	S-FCKP	P-TE
5	49A	P-CCPF	O-P	P-AF	P-CCPF	P-SIS	P-PF	P-PML	O-P	O-P	S-IS	P-TE
6	21B/49	A-JDME	A-V	P-AF	P-CCPF	S-IS	A-JDME	P-SIS	O-RAM	O-P	O-P	O-RAM
7	1810	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-SB	A-JDME	O-C	S-IS	S-IS	P-TE
8	1110	A-SB	O-P	P-AF	A-JDME	P-APS	A-SB	P-APS	S-IS	S-FCKP	S-FCKP	P-TE
9	1110	S-SV	A-SB	A-V	A-JDME	O-P	A-JDME	O-P	O-P	O-P	O-P	O-RAM
10	1110	S-SV	O-P	A-SB	P-CCPF	P-APS	A-JDME	P-APS	S-IS	O-P	O-P	P-TE
11	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	O-C	O-C	O-C	O-P	P-TE
12	1110	A-V	A-JDME	A-JDME	A-JDME	P-APS	P-CCPF	P-SIS	S-IS	S-FCKP	S-IS	P-TE
13	1110	A-V	P-CCPF	A-JDME	P-CCPF	P-APS	A-SB	P-APS	O-P	O-P	O-P	P-TE
14	1110	A-JDME	P-CCPF	S-FCKP	P-CCPF	P-SIS	A-SB	P-APS	S-FCKP	O-P	O-P	P-TE

HFACS-M		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	A-SB	A-JDME	A-JDME	P-CCPF	P-APS	A-SB	P-APS	C-IS	C-FCKP	C-IS	P-TE
2	1810	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	C-PIO	O-P	O-P	P-TE
3	0602	A-V	C-IS	P-AF	A-JDME	P-APS	P-AF	P-SIS	O-P	O-P	O-P	O-RAM
4	7523	A-JDME	A-SB	P-CCPF	A-JDME	P-APS	A-JDME	P-APS	P-TE	P-TE	C-IS	O-RAM
5	1310	A-SB	P-CCPF	A-JDME	P-CCPF	P-APS	A-JDME	P-APS	O-P	C-IS	C-IS	O-RAM
6	1120	A-V	P-CCPF	A-JDME	P-CCPF	O-P	A-JDME	P-PF	O-P	O-RAM	O-P	P-TE
7	19A	A-V	P-CCPF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	C-FCKP	O-P	C-SV	P-TE
8	1110	A-V	P-PBF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	O-C	P-TE
9	1110	A-SB	A-SB	P-AF	P-CCPF	P-APS	P-CCPF	P-APS	O-P	O-P	O-P	P-TE
10	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-SB	P-PF	C-IS	C-FCKP	C-IS	P-TE
11	1110	A-V	P-PML	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	O-C	O-RAM
12	1110	A-SB	A-JDME	A-JDME	A-JDME	O-P	A-JDME	P-APS	O-P	O-C	O-P	P-TE
13	1110	A-SB	P-CCPF	P-AF	P-CCPF	P-APS	A-JDME	P-APS	O-P	O-P	C-IS	O-P
14	1110	P-APS	P-CCPF	P-CCPF	P-CCPF	P-APS	A-JDME	P-APS	O-C	C-MPT	C-IS	O-RAM

C. DOD HFACS SUB

DOD SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	S-IS	S-FCKP	S-PIO	S-SV	O-RAM	O-C	O-P	Pi	
1	5	2	0	3	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0.176	14
2	2	1	0	1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	3	0.275	14
3	1	5	0	1	0	0	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0.275	14
4	0	3	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0.637	14
5	0	0	0	0	0	0	2	0	0	0	0	0	10	1	0	0	0	0	0	1	0.505	14
6	5	7	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0.341	14
7	0	1	0	0	0	0	2	0	0	1	1	0	7	0	0	0	0	0	1	1	0.242	14
8	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	1	1	2	5	0.187	14
9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	2	7	0.286	14
10	0	0	0	0	0	0	0	0	0	0	0	0	0	4	3	0	0	0	0	7	0.330	14
11	0	0	0	0	0	11	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0.615	14
Total	13	19	0	5	0	11	4	22	6	1	2	0	17	12	7	0	3	3	5	24	3.868	154
Pj	0.084	0.123	0.000	0.032	0.000	0.071	0.026	0.143	0.039	0.006	0.013	0.000	0.110	0.078	0.045	0.000	0.019	0.019	0.032	0.156		

Pbar = 0.352
PeBar = 0.098
Kappa = 0.281

DOD SWO SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	S-IS	S-FCKP	S-PIO	S-SV	O-RAM	O-C	O-P	Pi	
1	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0.143	7
2	1	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	2	0.190	7
3	1	2	0	1	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0.095	7
4	0	3	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0.429	7
5	0	0	0	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	1	0.476	7
6	3	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0.286	7
7	0	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	0	1	1	0.286	7
8	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	1	2	0.190	7
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	4	0.333	7
10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	5	0.476	7
11	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0.714	7
Total	7	10	0	3	0	6	2	8	2	0	0	0	9	4	5	0	2	1	3	15	3.619	77
Pj	0.091	0.130	0.000	0.039	0.000	0.078	0.026	0.104	0.026	0.000	0.000	0.000	0.117	0.052	0.065	0.000	0.026	0.013	0.039	0.195		

Pbar = 0.329
PeBar = 0.106
Kappa = 0.250

DOD NON SWO SUB	A-SB	A-JDME	A-PE	A-AV	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	S-IS	S-FCKP	S-PIO	S-SV	O-RAM	O-C	O-P	Pi	
1	3	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0.190	7
2	1	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0.286	7
3	0	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0.429	7
4	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	1.000	7
5	0	0	0	0	0	0	1	0	0	0	0	0	5	1	0	0	0	0	0	0	0.476	7
6	2	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.333	7
7	0	1	0	0	0	0	1	0	0	1	1	0	3	0	0	0	0	0	0	0	0.143	7
8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	3	0.143	7
9	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	3	0.286	7
10	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	2	0.238	7
11	0	0	0	0	0	5	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0.476	7
Total	6	9	0	2	0	5	2	14	4	1	2	0	8	8	2	0	1	2	2	9	4.000	77
Pj	0.078	0.117	0.000	0.026	0.000	0.065	0.026	0.182	0.052	0.013	0.026	0.000	0.104	0.104	0.026	0.000	0.013	0.026	0.026	0.117		

Pbar = 0.364
PeBar = 0.099
Kappa = 0.293

D. HFACS-M SUB

HFACS-M SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	C-IS	C-FCKP	C-MPT	C-PIO	C-SV	O-RAM	O-C	O-P	Pi	
1	7	1	0	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.341	14
2	2	2	0	0	0	0	0	7	0	1	0	1	0	1	0	0	0	0	0	0	0	0.253	14
3	0	4	0	0	0	0	0	4	6	0	0	0	0	0	0	0	0	0	0	0	0	0.297	14
4	0	3	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0.637	14
5	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	2	0.736	14
6	2	10	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.505	14
7	0	0	0	0	0	0	1	0	0	0	2	0	11	0	0	0	0	0	0	0	0	0.615	14
8	0	0	0	0	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	1	8	0.319	14
9	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	1	0	0	1	1	7	0.242	14
10	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0	2	5	0.286	14
11	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	5	0	1	0.418	14
Total	11	20	0	5	0	10	1	23	7	1	2	1	24	10	3	1	1	1	6	4	23	4.648	154
Pj	0.071	0.130	0.000	0.032	0.000	0.065	0.006	0.149	0.045	0.006	0.013	0.006	0.156	0.065	0.019	0.006	0.006	0.006	0.039	0.026	0.149		

Pbar = 0.423
PeBar = 0.105
Kappa = 0.355

HFACS-M SWO SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	C-IS	C-FCKP	C-MPT	C-PIO	C-SV	O-RAM	O-C	O-P	Pi	
1	4	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0.333	7
2	1	1	0	0	0	0	0	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0.143	7
3	0	1	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0.333	7
4	0	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0.714	7
5	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0.714	7
6	1	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.476	7
7	0	0	0	0	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	0	0.714	7
8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	5	0.476	7
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	4	0.286	7
10	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	2	0.238	7
11	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0.333	7
Total	6	8	0	2	0	4	0	12	4	1	1	1	13	4	1	1	0	0	2	4	13	4.762	77
Pj	0.078	0.104	0.000	0.026	0.000	0.052	0.000	0.156	0.052	0.013	0.013	0.013	0.169	0.052	0.013	0.013	0.000	0.000	0.026	0.052	0.169		

Pbar = 0.433
PeBar = 0.111
Kappa = 0.362

HFACS-M NON SWO SUB	A-SB	A-JDME	A-PE	A-V	P-PE	P-TE	P-SIS	P-CCPF	P-AF	P-PML	P-PF	P-PBF	P-APS	C-IS	C-FCKP	C-MPT	C-PIO	C-SV	O-RAM	O-C	O-P	Pi	
1	3	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.286	7
2	1	1	0	0	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0.286	7
3	0	3	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0.238	7
4	0	2	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.524	7
5	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0.714	7
6	1	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0.476	7
7	0	0	0	0	0	0	1	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0.476	7
8	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	3	0.143	7
9	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	3	0.143	7
10	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	3	0.286	7
11	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0.429	7
Total	5	12	0	3	0	6	1	11	3	0	1	0	11	6	2	0	1	1	4	0	10	4.000	77
Pj	0.065	0.156	0.000	0.039	0.000	0.078	0.013	0.143	0.039	0.000	0.013	0.000	0.143	0.078	0.026	0.000	0.013	0.013	0.052	0.000	0.130		

Pbar = 0.364
PeBar = 0.105
Kappa = 0.289

E. CATEGORICAL

DOD HFACS		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	49/15	A	P	A	P	P	A	P	O	O	O	P
2	1310	P	P	P	P	P	A	P	O	O	O	P
3	0602	A	A	A	P	P	A	P	O	O	O	P
4	7565	A	P	A	P	P	A	P	S	S	S	P
5	49A	P	O	P	P	P	P	P	O	O	S	P
6	21B/49	A	A	P	P	S	A	P	O	O	O	O
7	1810	A	P	P	P	P	A	A	O	S	S	P
8	1110	A	O	P	A	P	A	P	S	S	S	P
9	1110	S	A	A	A	O	A	O	O	O	O	O
10	1110	S	O	A	P	P	A	P	S	O	O	P
11	1110	A	P	P	P	P	A	O	O	O	O	P
12	1110	A	A	A	A	P	P	P	S	S	S	P
13	1110	A	P	A	P	P	A	P	O	O	O	P
14	1110	A	P	S	P	P	A	P	S	O	O	P

HFACS-M		Findings										
Number	Desig/MOS/AFSC	1	2	3	4	5	6	7	8	9	10	11
1	1317	A	A	A	P	P	A	P	C	C	C	P
2	1810	A	A	P	P	P	A	P	C	O	O	P
3	0602	A	C	P	A	P	P	P	O	O	O	O
4	7523	A	A	P	A	P	A	P	P	P	C	O
5	1310	A	P	A	P	P	A	P	O	C	C	O
6	1120	A	P	A	P	O	A	P	O	O	O	P
7	19A	A	P	P	P	P	A	P	C	O	C	P
8	1110	A	P	P	P	P	A	P	O	O	O	P
9	1110	A	A	P	P	P	P	P	O	O	O	P
10	1110	A	A	P	P	P	A	P	C	C	C	P
11	1110	A	P	P	P	P	A	P	O	O	O	O
12	1110	A	A	A	A	O	A	P	O	O	O	P
13	1110	A	A	P	P	P	A	P	O	O	C	O
14	1110	P	P	P	P	P	A	P	O	C	C	O

F. DOD HFACS CATA

DOD CAT	O	S	P	A	Pi
1	0	2	2	10	0.516
2	3	0	7	4	0.330
3	0	1	6	7	0.396
4	0	0	11	3	0.637
5	1	1	12	0	0.725
6	0	0	2	12	0.736
7	2	0	11	1	0.615
8	9	5	0	0	0.505
9	10	4	0	0	0.560
10	9	5	0	0	0.505
11	2	0	12	0	0.736
Total	36	18	63	37	6.264
Pj	0.234	0.117	0.409	0.240	
Pbar =	0.569				
PeBar =	0.293				
Kappa =	0.391				

OD SWO CA	O	S	P	A	Pi
1	0	2	0	5	0.524
2	2	0	3	2	0.238
3	0	1	2	4	0.333
4	0	0	4	3	0.429
5	1	0	6	0	0.714
6	0	0	1	6	0.714
7	2	0	5	0	0.524
8	3	4	0	0	0.429
9	5	2	0	0	0.524
10	5	2	0	0	0.524
11	1	0	6	0	0.714
Total	19	11	27	20	5.667
Pj	0.247	0.143	0.351	0.260	
Pbar =	0.515				
PeBar =	0.272				
Kappa =	0.334				

NON-SWO	O	S	P	A	Pi
1	0	0	2	5	0.524
2	1	0	4	2	0.333
3	0	0	4	3	0.429
4	0	0	7	0	1.000
5	0	1	6	0	0.714
6	0	0	1	6	0.714
7	0	0	6	1	0.714
8	6	1	0	0	0.714
9	5	2	0	0	0.524
10	4	3	0	0	0.429
11	1	0	6	0	0.714
Total	17	7	36	17	6.810
Pj	0.221	0.091	0.468	0.221	
Pbar =	0.619				
PeBar =	0.324				
Kappa =	0.436				

G. HFACS-M CATA

M CAT	O	C	P	A	Pi
1	0	0	1	13	0.857
2	0	1	6	7	0.396
3	0	0	10	4	0.560
4	0	0	11	3	0.637
5	2	0	12	0	0.736
6	0	0	2	12	0.736
7	0	0	14	0	1.000
8	9	4	1	0	0.462
9	9	4	1	0	0.462
10	7	7	0	0	0.462
11	6	0	8	0	0.473
Total	33	16	66	39	6.780
Pj	0.214	0.104	0.429	0.253	
Pbar =	0.616				
Pe Bar =	0.305				
Kappa =	0.448				

M SWO CAT	O	C	P	A	Pi
1	0	0	1	6	0.714
2	0	0	3	4	0.429
3	0	0	6	1	0.714
4	0	0	6	1	0.714
5	1	0	6	0	0.714
6	0	0	1	6	0.714
7	0	0	7	0	1.000
8	6	1	0	0	0.714
9	5	2	0	0	0.524
10	4	3	0	0	0.429
11	3	0	4	0	0.429
Total	19	6	34	18	7.095
Pj	0.247	0.078	0.442	0.234	
Pbar =	0.645				
Pe Bar =	0.317				
Kappa =	0.481				

M NON-SWO CAT	O	C	P	A	Pi
1	0	0	0	7	1.000
2	0	1	3	3	0.286
3	0	0	4	3	0.429
4	0	0	5	2	0.524
5	1	0	6	0	0.714
6	0	0	1	6	0.714
7	0	0	7	0	1.000
8	3	3	1	0	0.286
9	4	2	1	0	0.333
10	3	4	0	0	0.429
11	3	0	4	0	0.429
Total	14	10	32	21	6.143
Pj	0.182	0.130	0.416	0.273	
Pbar =	0.558				
Pe Bar =	0.297				
Kappa =	0.372				

H. OVERALL ANALYSIS

	DOD HFACS	HFACS-M
SWO	7	7
NON-SWO	7	7

	Overall	SWO	NON-SWO
DOD HFACS (Nano-code)	0.154	0.114	0.198
HFACS-M (Nano-code)	0.182	0.202	0.137
DOD HFACS (Sub-code)	0.281	0.25	0.293
HFACS-M (Sub-code)	0.355	0.362	0.289
DOD HFACS (Category)	0.391	0.334	0.436
HFACS-M (Category)	0.448	0.481	0.372

LIST OF REFERENCES

Baysari, M. T., Caponecchia, C., McIntosh, A. S., & Wilson, J. R. (2009). Classification of errors contributing to rail incidents and accidents: A comparison of two human error identification techniques. *Safety Science*, *47*, 948–957.

Defense Acquisition University [DAU]. (2009, September 15). Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=510172&lang=en-US

Department of Defense. (2005, January). *Department of defense human factors analysis and classification system: A mishap investigation and data analysis tool*. Washington, DC: Department of Defense.

Department of the Navy. (2005, January). *OPNAVINST 5102.1D: Navy & Marine Corps mishap and safety investigation reporting, and record keeping manual*. Washington, DC: Department of the Navy.

Fleiss, J. L. (1971). Measuring nominal scale agreement among many raters. *Psychological Bulletin*, *76*(5), 378–382.

Griggs, F. J. (2012). *A human factors analysis and classification system (HFACS) examination of commercial vessel accidents* (Master's thesis). Naval Postgraduate School, Monterey, CA.

Gwet, K. L. (2010) *Handbook of inter-rater reliability* (2nd Ed.). Gaithersburg: Advanced Analytics, LLC.

Hale, A., Walker, D., Walters, N., & Bolt, H. (2012). Developing the understanding of underlying causes of construction fatal accidents. *Safety Science,* 1–8.

Inglis, M., Sutton, J., & McRandle, B. (2007, January). human factors analysis of australian aviation accidents and comparison with the United States. *Australian Transport Safety Bureau*, 1–61.

Lacy, R. (1998). *Human factors analysis of U.S. Navy afloat mishaps* (Master's thesis). Naval Postgraduate School, Monterey, CA.

Lazzaretti, P. (2008). *HSI in the USN frigate community: Operational readiness and safety as a function of manning levels* (Master's thesis). Naval Postgraduate School, Monterey, CA.

Lenne, M. G., Salmon, P. M., Liu, C. C., & Trotter, M. (2011). A systems approach to accident causation in mining: An application of the HFACS method. *Accident Analysis and Prevention*, 1–7.

Naval Safety Center. (2007). *DoD Human Factors Analysis and Classification System (HFACS)*.

O'Connor, P. (2008, June). HFACS with an additional layer of granularity: validity and utility in accident analysis. *Aviation, Space, and Environmental Medicine*, *79*(6), 599–606.

O'Connor, P., Walliser, J., & Philips, E. (2010). Evaluation of a human factors analysis and classification system used by trained raters. *Aviation, Space, and Environmental Medicine*, *81*(10), 957–960.

O'Connor, P., & Walker, P. (2011). Evaluation of a human factors analysis and classification system as used by simulated mishap boards. *Aviation, Space, and Environmental Medicine*, *82*(1), 44–48.

Olsen, N. S., & Shorrock, S. T. (2010). Evaluation of the HFACS-ADF safety classification system: Inter-coder consensus and intra-coder consistency. *Accident Analysis and Prevention*, *42*, 437–444.

Patterson, J. M., & Shappell, S. A. (2010). Operator error and system deficiencies: Analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS. *Accident Analysis and Prevention, 42*, 1379–1385.

Rashid, H. S. J., Place, C. S., & Braithwaite, G. R. (2010). Helicopter maintenance error analysis: Beyond the third order of the HFACS-ME. *International Journal of Industrial Ergonomics*, *40*, 636–647.

Reason, J. (1990). *Human error*. Oakleigh, Victoria: Press Syndicate of the University of Cambridge.

Reason, J. (1997). *Managing the risks of organizational accidents*. Burlington, VT: Ashgate.

Reinach, S., Viale, A., & Green, D. (2007). Human error investigation software tool (HEIST). *U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development*, 1–41.

Salmon, P. M., Cornelissen, M., & Trotter, M. J. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. *Safety Science, 50*, 1158–1170.

Schmorrow, D. D. (1998). *A human error analysis and model of naval aviation maintenance related mishaps* (Master's thesis). Naval Postgraduate School, Monterey, CA.

Schroder-Hinrichs, J. U., Baldauf, M., & Ghirxi, K. T. (2011). Accident investigation reporting deficiencies related to organizational factors in machinery space fires and explosions. *Accident Analysis and Prevention, 43*(3), 1187–1196.

Shappell, S. A., & Wiegmann, D. A. (2001). Applying reason: The human factors analysis and classification system (HFACS). *Human Factors and Aerospace Safety, 1*(1), 59–86.

Wang, L., Wang, Y., Yang, X., Cheng, K., Yang, H., Zhu, B., Fan, C., & Ji, X. (2011). Coding ATC incident data using HFACS: Intercoder consensus. *International Journal of Quality, Statistics, and Reliability*, 1–8.

Wertheim, K. E. (2010). Human factors in large-scale biometric systems: A study of the human factors related to errors in semiautomatic fingerprint biometrics. *IEEE Systems Journal*, *4*(2), 138–146.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California